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Cohesive Traction-Separation Laws for Tearing of Ductile Metal Plates

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ABSTRACT

Traction-separation laws are an essential component of finite element methods currently under development for analyzing fracture of large scale plate or shell structures. The failure process ahead of a Mode I crack advancing in a thin ductile metal plate or sheet produces plastic dissipation through a sequence of deformation steps that include necking well ahead of the crack tip and shear localization followed by a slant fracture in the necked region somewhat closer to the tip (see Fig. 1). The objective of this work is to analyze this sequential process to characterize the traction-separation behavior and the associated effective cohesive fracture energy of the entire failure process. The emphasis is on what is often described as plane stress behavior taking place after the crack tip has advanced a distance of one or two plate thicknesses. The present study resolves the sequence of failure details using the Gurson constitutive law based on the micromechanics of the ductile fracture process, including a recent extension that accounts for damage growth in shear. As localization takes place in front of the advancing crack additional

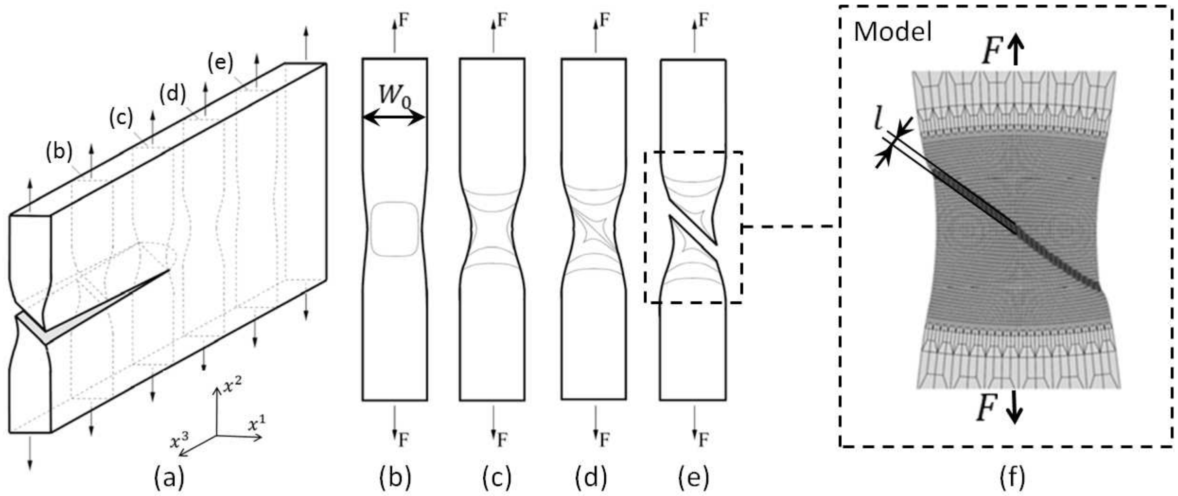

Figure 1: (a) Schematic of the sequential fracture process governing crack advance in ductile sheet metal subject to Mode I loading, (b) onset of local necking, (c) local thinning, (d) shear localization, (e) slant failure and (f) the corresponding 2D micromechanics based model (see also [1]).

straining along the crack are essentially zero ($\dot{\varepsilon}_{33} = 0$). Thus, the fracture process can be approximated by a 2D plane strain finite element model (see Fig. 1). This allows for an intensive parametric study and a detail treatment of the crack growth phenomenon, which fits into the framework of plane stress growth considered more broadly in [2]. The deformation history relevant to a cohesive zone for a large scale model is identified and the traction-separation relation is determined, including the dissipated energy. The total dissipated energy/area, Γ_0, associated with a cohesive zone model of ductile plates subject to Mode I tearing are tied to the energy dissipated during necking, shear localization and slant fracture following the onset of necking in the zone ahead of the crack tip. For the sequence considered here, it is shown that the energy/area can be partitioned as $\Gamma_0 = \Gamma_I + \Gamma_{II}$, with Γ_I as the energy/area dissipated between the onset of necking and the onset of shear localization, and Γ_{II} as that dissipated in shear localization and shear fracture. The first contribution, Γ_I, dominates the total energy dissipated during crack advance and it scales exactly with the plate thickness, W_0, according to $\Gamma_I \propto \sigma_y W_0$, where σ_y is the initial yield stress. By contrast, the second contribution scales as $\Gamma_{II} \propto \sigma_y l$, where l is the thickness of the shear localization band, which is set by the element size in the presented FE analysis (see Fig. 1). In the case $\sigma_y = 300$MPa, one finds that $\Gamma_I \sim 1$MJm^{-2} and $\Gamma_{II} \sim 0.01$MJm^{-2}, which highlights the fact that because plasticity constitutes the major portion of the dissipation for both contributions, each of them is huge compared to the atomistic work of separation (typically only several Jm^{-2}). Furthermore, this example clearly demonstrates that $\Gamma_I \gg \Gamma_{II}$.

The cohesive zone characterized in this work is associated with a Mode I crack that has propagated several plate thicknesses such that the zone ahead of the crack tip is fully developed. The transition from an initial propagation phase is thereby omitted and the treatment of this is in the need to be worked out. In spite, employing the cohesive zone laws extracted using the presented approach has proven to capture the load-deflection behavior under tearing quite accurately when compared to the experimental findings in [3]. Thus, it is believed that the potential for this approach is considerable for cases where the tearing resistance of plate and shell structures is a concern.

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