Why Cutting Strength is an Indicator of Fatigue Threshold

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Crack tip fields during cutting and tensile loading have been computed via finite element analysis, and measured using Digital Image Correlation during experiments executed on the Coesfeld Intrinsic Strength Analyser. The results show that cutting with a sharp blade while the specimen is under a small amount of tension produces a much-reduced dissipative process zone in front of the crack tip, in comparison with the process zone produced by tensile loading alone at nominally similar conditions. Because the energy released by a growing crack supplies both the process of breaking polymer chains to form crack faces, and the dissipative process at the crack tip, minimizing crack tip dissipation causes the observed remaining energy release rate during a cutting experiment to approach the limit reflecting the breakage of polymer chains. Conveniently, this implies that a relatively brief cutting experiment may be used as an indicator of long-term fatigue behavior.

Keywords: Intrinsic Strength, Cutting, Fatigue Threshold, Fracture Mechanics

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At constant crack growth rate, the energy release rate of a crack includes both the intrinsic strength T_0 required to break polymer chains crossing the plane of the crack and the process zone dissipation T_z, which is a function of the strain level ε, strain rate $\dot{\varepsilon}$, temperature θ and R ratio. The cutting experiment aims to minimize T_z by minimizing the size of the crack tip process zone.

$$T = T_0 + T_z(\varepsilon, \dot{\varepsilon}, \theta, R)$$

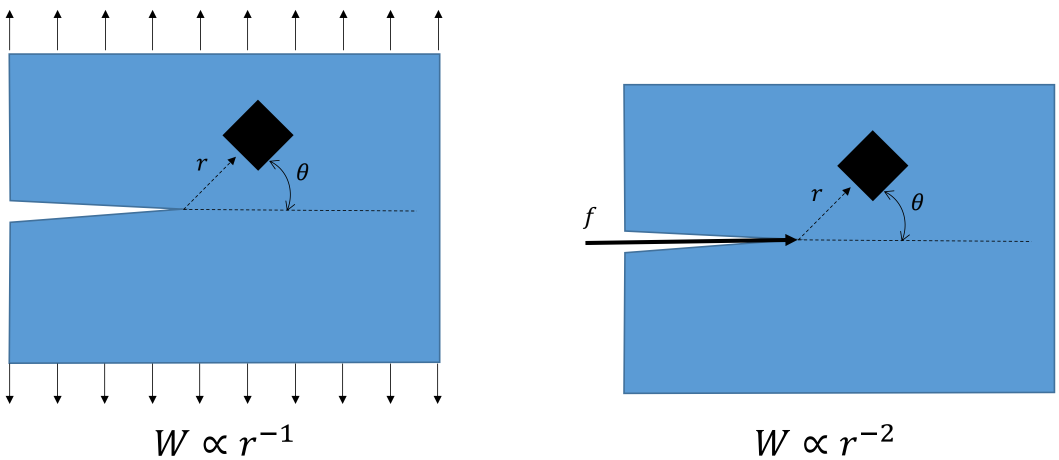

Figure 1. According to Linear Elastic Fracture Mechanics, the strain energy density distribution at the crack tip is singular for both the edge-cracked tension case and for the point load / cutting case. The strength of the singularity (ie the exponent on radius r) differs by a factor of 2, however, so that the cutting case stores and dissipates much less total energy than the tension case.

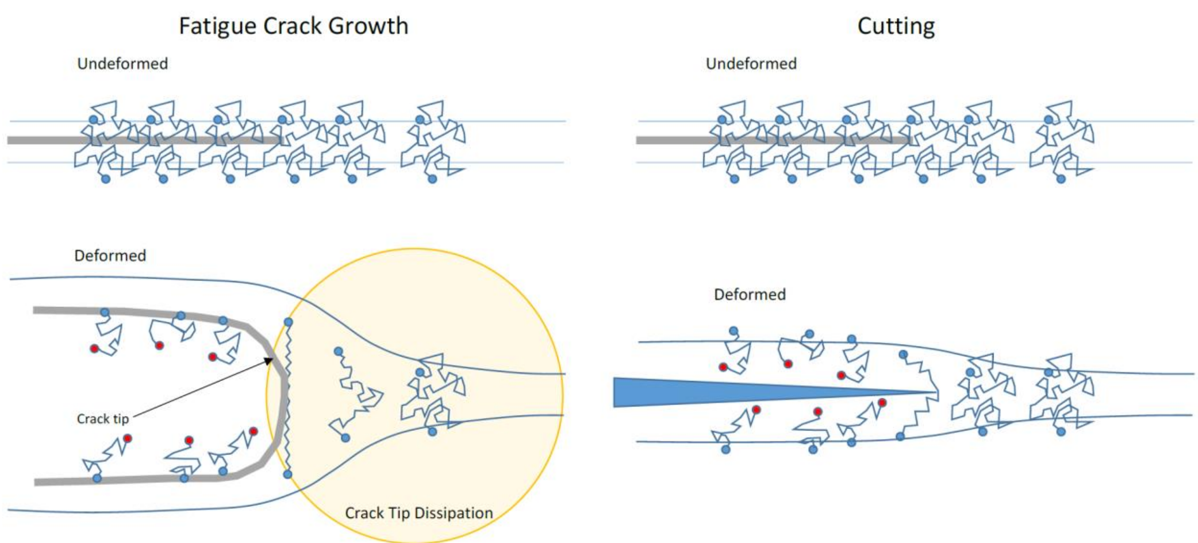

Figure 2. A crack loaded under far-field tension consumes energy via dissipation in the crack tip process zone, and via the breakage of polymer chains at the tip. A crack loaded by a sufficiently sharp blade minimizes any process zone by applying load directly to the chain at the crack tip.

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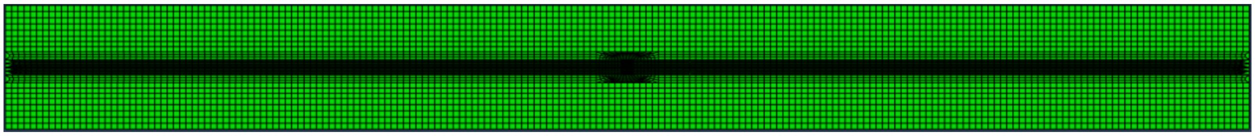

Figure 3. Finite Element Model of the edge-cracked planar tension specimen used for cutting and crack growth experiments. The crack tip is located at the highly refined center of the specimen.

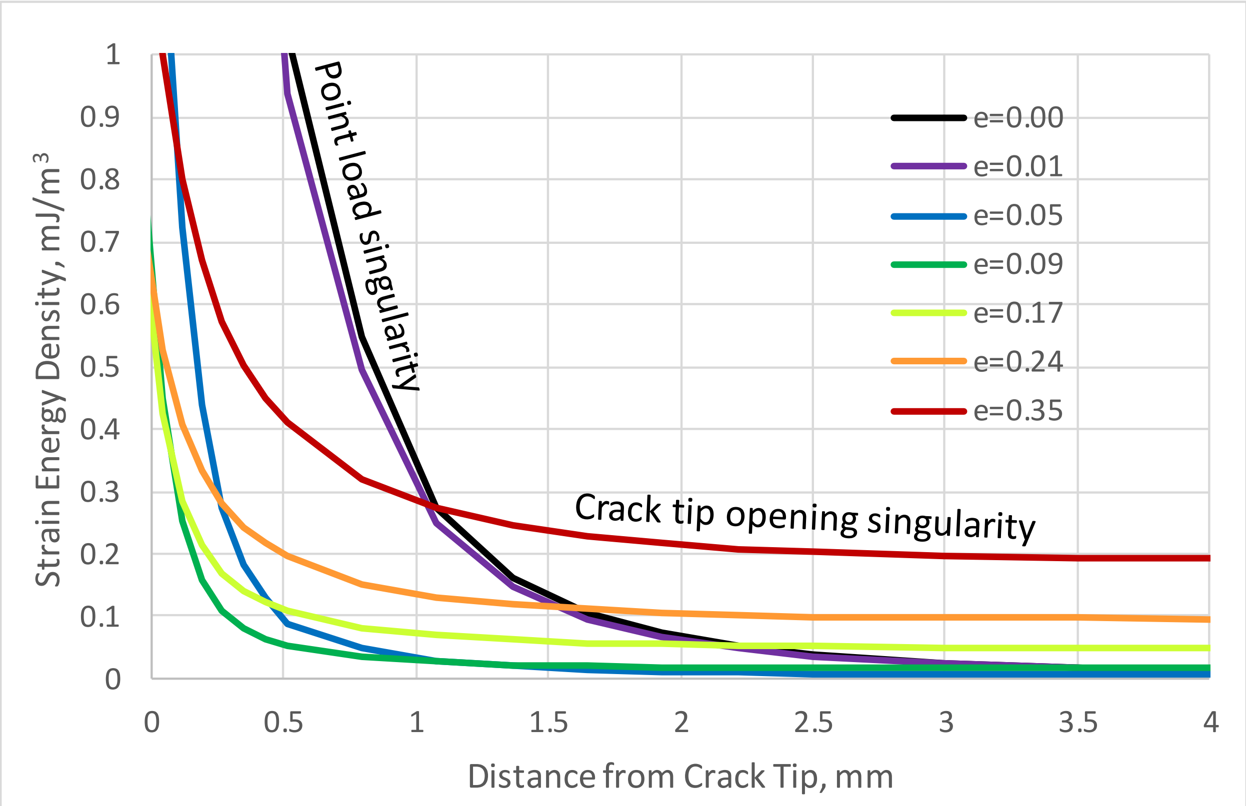

Figure 4. Strain energy density distribution with distance from crack tip, for varying amounts of opening strain on the pure shear specimen plus a point load with magnitude equal to the experimentally observed cutting force. The crack tip process zone is minimized in this case at an opening strain of 9%.

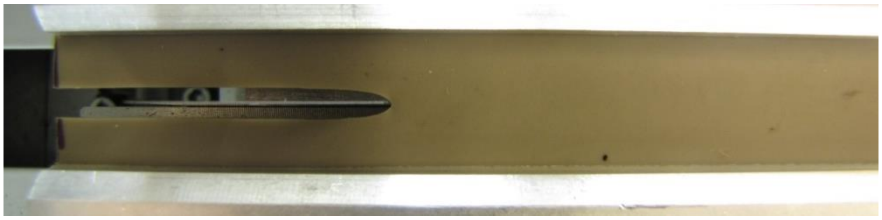

Figure 5. Blade-loaded, edge-cracked planar tension specimen under load during cutting on the Coesfeld Intrinsic Strength Analyser.