CTOD: Crack tip opening displacement

T.L. Anderson. Chap.3 Elastic-plastic Fracture Mechanics

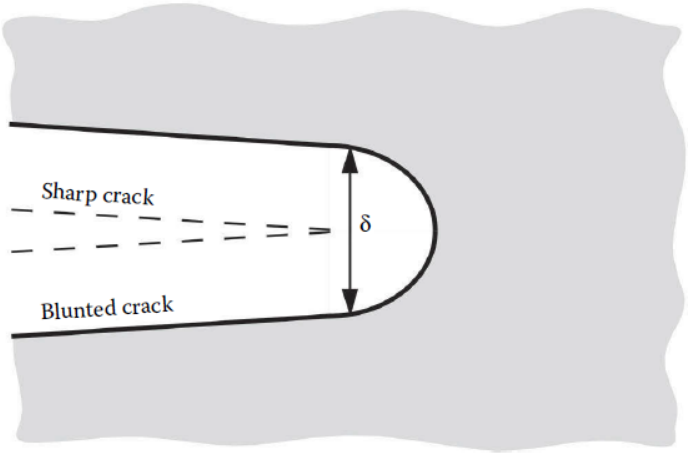

FIGURE 3.1
Crack tip opening displacement (CTOD). An initially sharp crack blunts with plastic deformation, resulting in a finite displacement (δ) at the crack tip.

Wells, A.A., Unstable crack propagation in metals: Cleavage and fast fracture. *Proceedings of the Crack Propagation Symposium*, Vol. 1, Paper 84, Cranfield, UK, 1961.

CTOD: Crack tip opening displacement

TABLE 2.2

Crack Tip Displacement Fields for Modes I and II (Linear Elastic, Isotropic Material)

	Mode I	Mode II
u_x	$\frac{K_I}{2\mu}\sqrt{\frac{r}{2\pi}}\cos\left(\frac{\theta}{2}\right)\left[\kappa-1+2\sin^2\left(\frac{\theta}{2}\right)\right]$	$\frac{K_{II}}{2\mu}\sqrt{\frac{r}{2\pi}}\sin\left(\frac{\theta}{2}\right)\left[\kappa+1+2\cos^2\left(\frac{\theta}{2}\right)\right]$
u_y	$\frac{K_I}{2\mu}\sqrt{\frac{r}{2\pi}}\sin\left(\frac{\theta}{2}\right)\left[\kappa+1-2\cos^2\left(\frac{\theta}{2}\right)\right]$	$-\frac{K_{II}}{2\mu}\sqrt{\frac{r}{2\pi}}\cos\left(\frac{\theta}{2}\right)\left[\kappa-1-2\sin^2\left(\frac{\theta}{2}\right)\right]$

Note: μ is the shear modulus; $\kappa = 3 - 4\nu$ (plane strain); $\kappa = (3 - \nu)/(1 + \nu)$ (plane stress).

In mode I:

$$u_y = \frac{K_I}{2\mu}\sqrt{\frac{r}{2\pi}}[\kappa+1] \text{ at } \theta = \pi \text{ with } \kappa = 3\text{-}4\nu \text{ in PE and } \kappa = (3\text{-}\nu)/(1+\upsilon) \text{ in PS}$$

CTOD: Crack tip opening displacement

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CTOD using the Irwin estimation of the plastic zone size, r_y

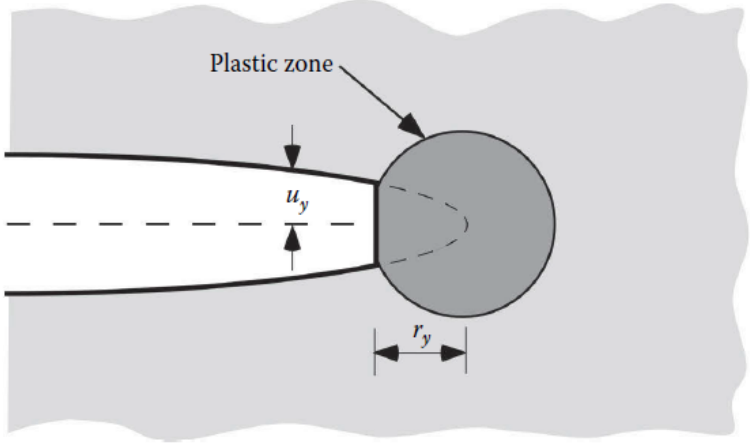

FIGURE 3.2
Estimation of CTOD from the displacement of the effective crack in the Irwin plastic zone correction.

$$\delta = 2u_y = \frac{4}{\pi}\frac{K_I^2}{\sigma_{YS}E} = \frac{4}{\pi}\frac{\mathcal{G}}{\sigma_{YS}}$$

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CTOD using the Yield strip model with a plastic zone size ρ

$$\rho = \frac{\pi^2 \sigma^2 a}{8\sigma_{YS^2}} = \frac{\pi}{8}\left(\frac{K_I}{\sigma_{YS}}\right)^2$$

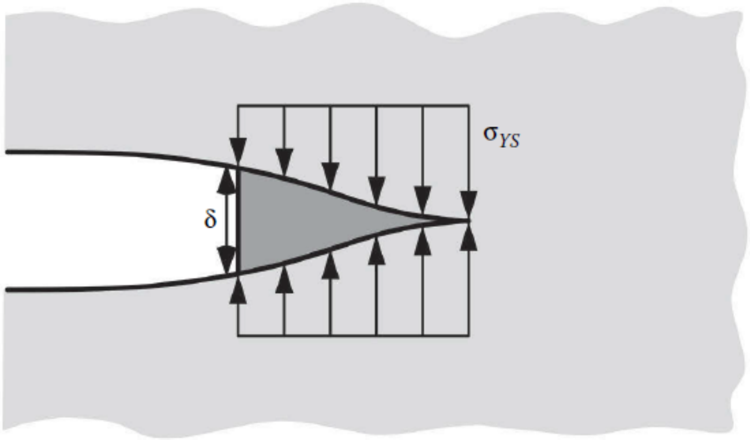

FIGURE 3.3
Estimation of CTOD from the strip yield model.

$$\delta = 2\frac{G}{\sigma_{YS}} \quad \text{thus} \quad G = \frac{1}{2}\delta\sigma_{YS} \left[\mathrm{J/m^2}\right] \text{ with G, the energy release rate}$$

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CTOD can be measured on edge-cracked specimens loaded in 3 point bending

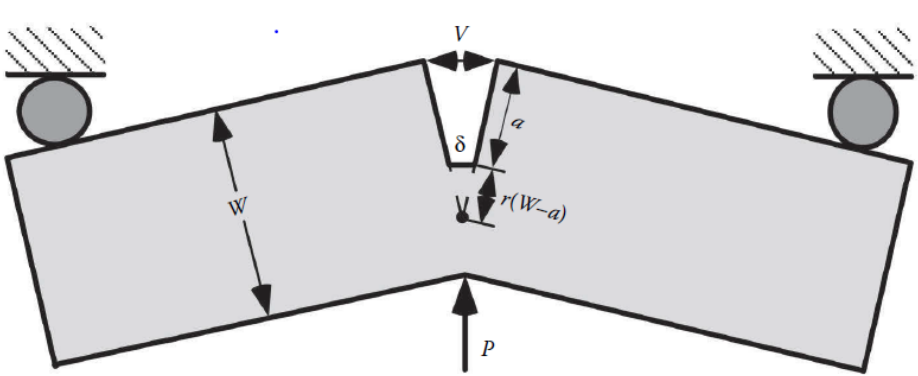

FIGURE 3.5
The hinge model for estimating CTOD from three-point bend specimens.

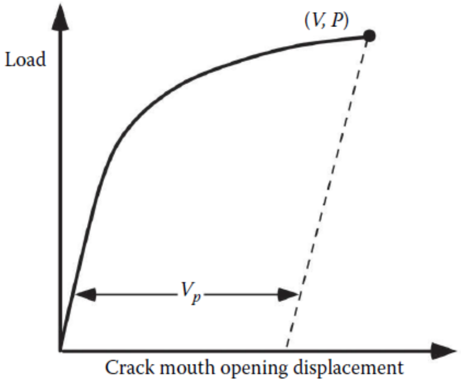

FIGURE 3.6
Determination of the plastic component of the crack mouth opening displacement.

$$\frac{\delta}{r(W-a)} = \frac{V}{r(W-a)+a}$$

$$\delta = \frac{r(W-a)V}{r(W-a)+a}$$

$$V = V_{el} + V_{pl}$$

$$\delta = \delta_{el} + \delta_p = \frac{K_I^2}{m\sigma_{YS}E'} + \frac{r_p(W-a)V_p}{r_p(W-a)+a}$$

$r_p = 0.44$ (plastic rotational factor)

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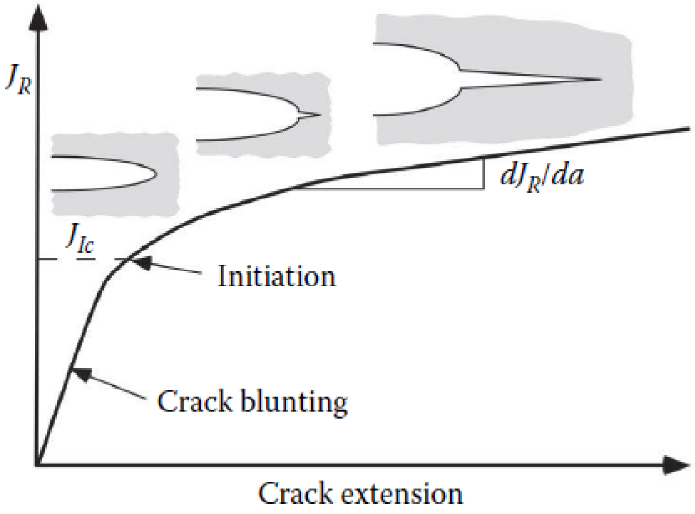

FIGURE 3.19
Schematic J resistance curve for a ductile material.

Typical J resistance curve for a ductile material. In the initial stages of deformation, the R curve is relatively steep; there is a small amount of apparent crack growth due to blunting. As J increases, the material at the crack tip fails locally and the crack advances further.

EPFL

Fracture mechanics
Last class on May 26th

- Recap and Q&As

- Fracture mechanics, T.L. Anderson
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