CRACKING STABILITY IN TAPERED DCB TEST PIECES

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With the increasing acceptance of DCB test pieces for fracture toughness determinations, many investigators are now interested in modifying the basic design to suit their own requirements. The arms are no longer parallel but contoured or for simplicity of manufacture, tapered so that a constant crack extension force R or stress intensity factor K is available under constant applied loads for a certain range of crack length. This particular design is very often employed in studies of environmental cracking and of standard fracture toughness testing of materials. However, experiments have shown that if not properly designed, the test piece may fail catastrophically under either monotonic increasing load or displacement. Further, the crack length over which K or R is invariant may be too short for experimental usefulness; and added to this, the crack may veer out of the arms during propagation. Since relatively little work has been done on cracking stability in these tapered DCB specimens, we have, in the present note, attempted to illustrate some of the results we have found for this particular problem.

Consider a tapered DCB specimen of constant thickness t, with equal and opposite forces X applied at a distance e from the apex. (See inset in Figure 1.) A crack of length $0 < a < W$ was considered to spread from the apex and along the center line. By taking into account the crack end effects, we obtain the compliance expression as

$$C_1 = (u/X)_1 = (2\Gamma^2/\alpha E t)\,\{(0.49 + 1.4/\alpha + 1/\alpha^2)\ln\,[1 + (a/W)/(e/W)] + 2(e/W)/(a/W+e/W) - 1.5 - 0.5(e/W)^2/(a/W + e/W)^2\} \qquad (1)$$

where Γ is the Srawley and Gross parameter [1]; α, the measure of the slope of the taper; and E, Young's modulus of the material. Figure 1 shows a comparison of the theoretical and experimental compliances obtained for 0.635 cm thick PMMA sheets with two different values of α. The correlation is found to be good.

Also, the fracture load predictions may be written as

$$X^*/\sqrt{(ERW)} = (\sqrt{\alpha}/\Gamma)\,\sqrt{(a/W + e/W)}/\{0.7 + (1/\alpha)[1 + (e/W)/(a/W)]^{-1}\} \qquad (2)$$

where X^* is the fracture load per unit thickness. Figure 2 shows a plot of $X^*/\sqrt{ERW}$ against (a/w) for $\alpha = 0.140$ and 0.268. It may be seen that for $a/W < 0.7$, experimental results are in good agreement with theoretical predictions. In fact, we have computed a series of curves for varying α and have observed that if $\alpha < 0.20$, the fracture load is quite constant over a reasonable range of crack length. However, our experience suggests that test pieces which are usually slender (because of small α), the crack has a strong tendency to run away from the center line and veer out of the arms. For increasing α (>0.50), though the crack gets more restrictions to run along the mid-plane, the range of crack length a over which R or K is constant may become very small. Thus, in proper specimen design, considerations have to be made on these factors.

Crack stability is yet another factor to consider because meaningful results on R or K are only obtained when the cracking is quasi-static. By using equation (2.10) of [2], we may obtain the stability criterion for cracking these tapered DCB test pieces under a hard testing machine in which $du/u > 0$, as

$$(1/R)\ dR/da > n_u/a \tag{3}$$

where n_u is a complicated function of a/W, e/W, and α. For simplicity, n_u is plotted against (a/W) for varying α in Figure 3. It may be seen that, when compared with DCB test pieces with parallel arms [3], the tapers destablise the cracking as in agreement with our experimental observations. This effect of destabilization is more severe with increasing slope of the taper α. We hope that this relatively significant point on cracking stability should not be left unnoted in the future design problems.

Interestingly enough, if we consider splitting of the tapered specimen as shown inset in Figure 4, by neglecting crack end effects, the compliance relation may be expressed as,

$$C_2 = (u/X)_2 = (24/\alpha^3Et)\ [1.5-\ln(1-a/W) - 2/(1-a/W) + 0.5/(1-a/W)^2] \tag{4}$$

Obviously, without going into details of derivation, the load to cause quasi-static cracking will drop continuously with increasing (a/W). Although this design does not seem suitable for stress corrosion cracking studies, it can serve, however, as an alternative means to obtain valid fracture toughness results. Experimental evidence shows that cracking is always along the center line because the ratio σ_y/σ_x which determines the direction of the crack path has been better controlled [4]. Manipulations on the stability criterion gives, for $du/u > 0$, the same form of (3). However, as shown in Figure 4, n_u becomes very negative as a/W increases. Thus, stability of cracking is easily achieved and crack turning better controlled in this loading arrangement of the tapered DCB specimen.

REFERENCES

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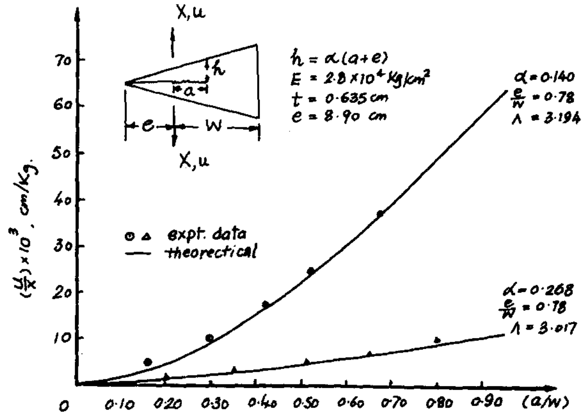

Figure 1. A comparison of theoretical and experimental compliances for PMMA.

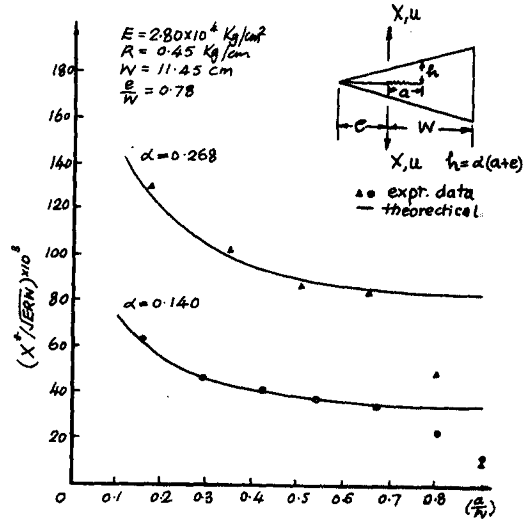

Figure 2. A comparison of theoretical and experimental fracture loads for PMMA.

Figure 3. A plot of n_u vs a/W with varying α.

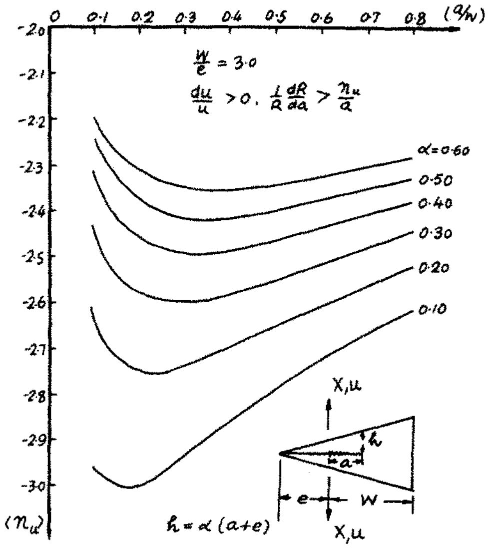

Figure 4. A plot of n_u vs a/W.