

YIELD ZONES IN POLYCARBONATE DCB TESTPIECES

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In a previous report [1], the author described the use of grooved DCB testpieces to obtain the fracture toughness (R) - crack velocity (L) relationship for polycarbonate. It was then noted that when plane strain conditions prevailed, the fracture plane was flat with little plastic flow of material at the crack tip. Crack spreading was usually unstable and the toughness values were low. However, when fracture was quasi-static and in a mixed mode condition giving high fracture toughness values, noticeable plastic yield strips along the grooves were observed at the crack tip. Some later experiments have shown that the brittle-ductile transition in a given testpiece was largely controlled by the growth and size of the plastic zone developed at the crack tip vicinity, which in turn depended on the loading rate of the testing machine and the effective thickness of the testpiece.

As an extension, experiments were run on similar DCB testpieces (see inset in Figure 1) with various groove dimensions to determine the relation between the plastic zone size p and $(K/\sigma_y)^2$ where K and σ_y are the applied stress intensity level and yield stress of polycarbonate. These results are reported here.

The beam on elastic foundation model has been used successfully in fracture toughness measurements [2,3] and employed in the present analysis. It may be shown that

$$K = \frac{2\sqrt{3} X/\lambda}{\sqrt{(t t_n d^3)}} F(\lambda r) \quad (1)$$

where d is the half beam depth, t the nominal thickness, t_n the effective thickness of the fracture plane, X the applied load, r the length of the elastic foundation, and λ the foundation modulus. The dimensionless term $F(\lambda r)$ may be determined from

$$F(\lambda r) = \frac{[\sinh(\lambda r)\cosh(\lambda r) - \sin(\lambda r)\cos(\lambda r) + \lambda L(\sinh^2(\lambda r) + \sin^2(\lambda r))]}{[\sinh^2(\lambda r) - \sin^2(\lambda r)]}$$

where L is the crack length.

For a given crack length, loads were applied and released slowly, corresponding to a small crosshead separation rate of the Instron testing machine (5 mm/min). The furthest extent of the plastic zone was measured by a $\times 50$ travelling microscope while under load and, in some high K level measurements, p was measured after unloading. By extending the crack length along the groove and reloading to different K -levels, many $[p, (K/\sigma_y)^2]$ data were generated in a single testpiece.

Figure 1 shows the correlation between these two quantities. In

general, the relation may be expressed as

$$p = m(K/\sigma_y)^2 + C \quad (2)$$

where

$$m = 0.16, C = 0, \text{ for } 0 < (K/\sigma_y)^2 \leq 5 \text{ mm} \quad (3)$$

$$m = 0.47, C = -1.50, \text{ for } 5 \text{ mm} < (K/\sigma_y)^2 < 28 \text{ mm} \quad (4)$$

It is interesting to note that the kink at $(K/\sigma_y)^2 = 5 \text{ mm}$ divides the fracture mode into two distinct regions characterised by plane strain and plane stress conditions. For fracture in the plane strain mode, the $p - (K/\sigma_y)^2$ relation (2,3) agrees well with that reported by Hahn et al. [4] for DCB Fe-3Si steel specimens. Experiments showed that some testpieces with $t_n = 4 \text{ mm}$ occasionally fractured in a brittle fashion during the p measurements upon loading. The plane strain fracture toughness obtained was about 7 kJ/m^2 . However, when fracture survived this plane strain K level, large plasticity effects occurred around the crack tip region. The $p - (K/\sigma_y)^2$ relation represented by (2) and (4), with a slope three times as much, will hold for the plane stress fracture condition. The yield zone was transformed from a plastic hinge geometry (plane strain) to a long narrow strip along the groove, resembling that of a Dugdale wedge model (plane stress). Cracking in the plastically deformed material was initiated when R was roughly 40 kJ/m^2 .

Note that although theoretically possible, the plastic zone characteristic associated with stress states in the plane strain condition has not been revealed in all the 2 mm thick testpieces because of experimental difficulties. In fact, for this net section thickness (i.e. 2 mm), fracture was always in the plane stress mode.

The effects of groove dimensions on the growth of the plastic zone were also studied. For the present test geometry, with $t_n = 2 \text{ mm}$ and 4 mm , it was found that the width of the groove (3, 6.5, and 9 mm) did not significantly affect the growth of the plastic zone which was single-valued in $(K/\sigma_y)^2$. This perhaps ruled out the possibility that the slope increase (in the plane stress condition) was due to the constraints of the grooves forcing the plastic zone to grow in the lengthwise dimension.

REFERENCES

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6 September 1974

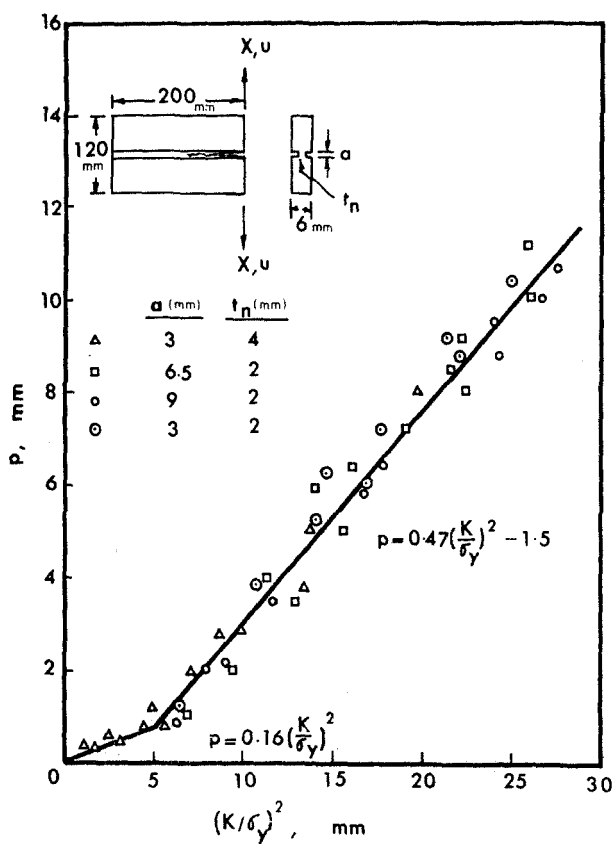


Figure 1. Correlation of p and $(K/\sigma_y)^2$