Letters

Fracture toughness of ABS

The use of fracture mechanics to describe the behaviour of rubber-toughened polymers has been attempted by various authors with wide variation in the results. This occurs because of the propensity of these materials to craze. The craze zone is usually so large as to render the results inapplicable in terms of fracture mechanics [1–5], as is shown for the compact tension specimen seen in Fig. 1.

However, useful information can still be obtained with a properly designed fracture toughness specimen which restricts the size of the crazed zone. Such a specimen was described by Parvin and Williams [6] for use with polymers. It has been described previously by Irwin in 1962 [7] following Sneddon's stress analysis of a penny-shaped crack 1946 [8]. Williams used the surface notch specimen for a 4% rubber-toughened polystyrene [6]. This note describes the use of this specimen in ABS samples with 22.5% and 30% rubber.

The values of the fracture toughness determined are called K_C because they are not K_{IC} values. The K_C value in polymer blends with such high rubber content must represent the combination of the K_{IC} of the matrix polymer and some other fracture toughness associated with crazing. This specimen configuration minimizes the amount of crazing and therefore gives a useful, if not exact fracture toughness value. That this is true can be seen in the available data on the fracture toughness of ABS. Most workers report values of J_{IC} that are 20 to 50 kJ m^{-2} [5, 13]. The specimens tested are variations of the edge notch specimen and are typically 3 to 10 mm thick. Table I compares the values obtained with the literature. It is clear that the values in the literature possess a very sizeable contribution from the plastic deformation mechanism of crazing. The fracture toughness of the matrix SAN is the smallest value one would expect. The surface notch specimen gives reasonable values of fracture toughness for a plane strain stress state. The other specimens may be more indicative of the plane stress condition [10–12]. Newmann and Williams [4] recently reported fracture toughness values for ABS determined through a tedious method which measured the craze volume using an Izod specimen. Their values are quite similar to the values reported here.

The fracture surfaces produced by the failure of the surface notch specimen show the same morphology as those seen on field failures. Owing to proprietary reasons those micrographs cannot be shown or discussed further.

The specimen dimensions were as follows:

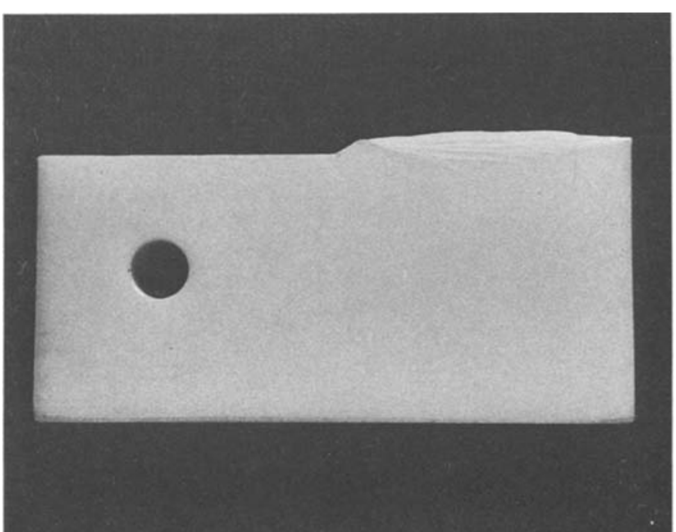

Figure 1 Compact tension specimen after test. The direction of crack growth is from left to right.

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TABLE I Fracture toughness compared to other investigators' results

Geometry	J_{IC} (kJ m^{-2})	K_{IC} (MN m$^{-3/2}$)	Material
SEN tension (3 mm thick)	25–33*		ABS [5]
SEN tension (10 mm thick)	23–25*		ABS [5]
CTS (10 mm thick)	22–26*		ABS [5]
Charpy, Izod	49*		ABS [3] (13% R)
Charpy	28*		ABS [15]
Izod	3.05†	2.8*	ABS [14] ($E = 2160$ MN m^{-2})
SN (15 mm thick)	3.64†	2.77	ABS (22.5% R)
SN (15 mm thick)	5.25†	3.12	ABS (30% R)
SN (7 mm thick)	0.22†	0.95	SAN

*As reported.
†Recalculated for comparison using $J_{IC} \approx G_{IC} = (K_{IC}^2/E)(1-\nu^2)$. $\nu \simeq 0.4$ for glassy polymers.
Young's modulus $E = 3447$ MN m^{-2}, SAN; $E = 1772$ MN m^{-2}, ABS (22.5% R); $E = 1558$ MN m^{-2}, ABS (30% R); $E = 2689$ MN m^{-2}, ABS (13% R).

250 mm x 85 mm x 15 mm. The gauge length was 100 mm x 50 mm with a notch cut by a sharp fly cutter in the centre perpendicular to the long axis of the specimen on the face 50 mm x 10 mm. The notch depth varied from 3 to 7 mm.

The drawing and photograph shown in Fig. 2 show the limited extent of the crazed zone.

One can estimate the minimum size of the crazed zone in a glassy polymer from the work of Argon and Hanoosh [9]. They established experimentally an intrinsic crazing stress of 50 MPa for polystyrene. If one uses the K_{IC} of Williams [6] of 1 MN m$^{-3/2}$ and using Irwin's [7] estimate of the plastic zone

$$r_y = \frac{K_{IC}^2}{(4\pi\sqrt{2})\sigma_y^2}$$

where σ_y = yield strength, then the minimum size $r_y = 2.26 \times 10^{-2}$ mm. In an SAN polymer, K_{IC} would be somewhat larger and if rubber-roughened, the blend would have a lower yield stress. Both factors would give a larger plastic zone. Fig. 2

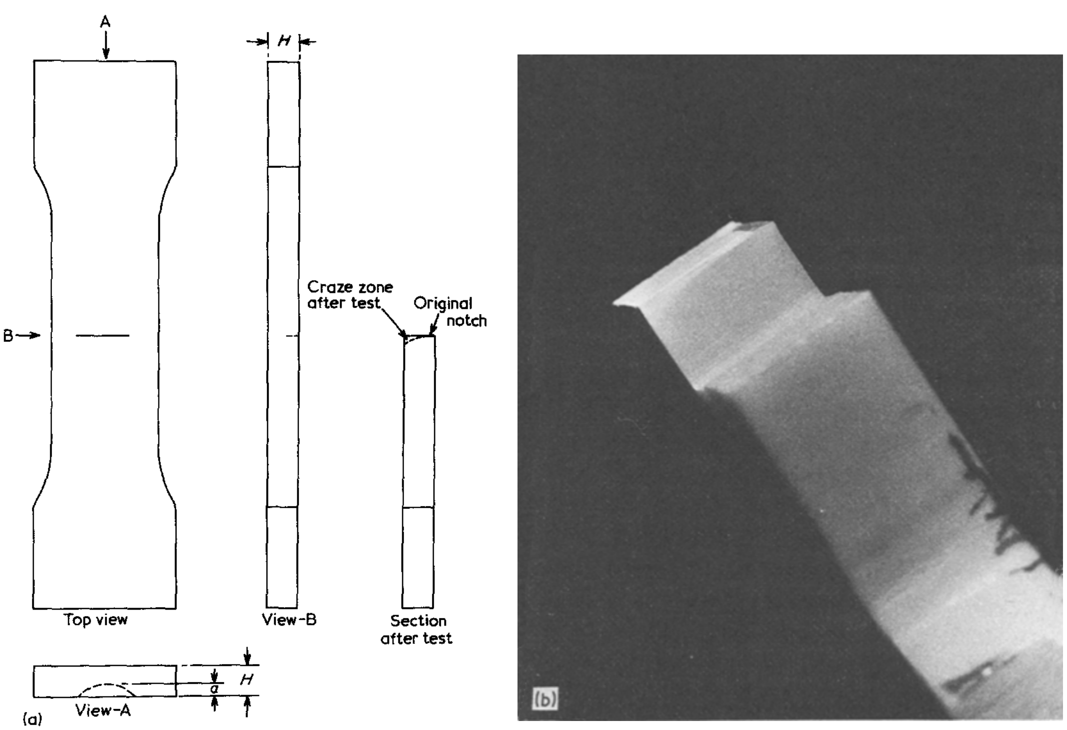

Figure 2 (a) Surface notch specimen. (b) Surface notch specimen after test.

TABLE II Fracture toughness

Geometry	Material	K_C ($MN\,m^{-3/2}$)
Surface notch (SN) 15 mm thick	ABS (22.5% rubber)	2.77
Surface notch 15 mm thick	ABS (30% rubber)	3.12
Surface notch 7 mm thick	SAN (matrix)	0.95

shows a crazed zone of ~0.3 mm which approaches the minimum expected in such a system.

When the data from such an experiment are plotted as $\sigma^2 Y^2$ versus $1/a (K^2 = \sigma^2 Y^2 a)$, the resultant straight line has a correlation factor greater than 0.95. The line was determined using a linear regression fit to the data points; each of which represent five specimens. This was true for the two ABS samples of different rubber levels and for notch dimensions of three different sizes.

Data are shown for the ABS materials of one notch dimension. Fig. 3 and Table II show the K_C values. These values are more representative of the plane strain fracture toughness.

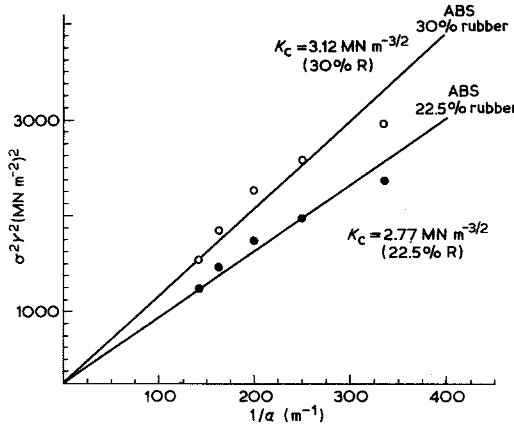

Figure 3 Fracture toughness data.

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H. J. NUSBAUM
E. I. du Pont de Nemours and Co., Pioneering Research Laboratory, Experimental Station, Wilmington, Delaware 19898, USA

High temperature interactions of metal oxides with rhenium in vacuo

Among the high temperature metals, rhenium and tungsten are the only two elements that have melting points over 3000° C. For use as high temperature devices, rhenium has probably more suitable properties than tungsten as the latter become brittle upon heating to a high temperature. Considerable data are available in the literature on the reactions of metal oxides with refractory metals, [1, 2] but there are few published data on the high temperature interactions of rhenium with metal oxides above 2000° C.

A pure rhenium metal boat of 0.0025 cm thickness, 0.4 cm wide and about 2 cm long was placed

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