J-integral Characterization of Impact-modified Polymers

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ABSTRACT

The fracture toughness of impact-modified polymers can be characterized by the J-integral. The use of the "crack blunting line", however is not justified. A direct observation of the crack initiation process can be made, which avoids the ambiguity associated with fracture surface measurements.

KEYWORDS

Fracture toughness; J-integral; toughened plastics; fracture; impact modification.

INTRODUCTION

The fracture toughness of four impact-modified polymers was characterized by the J-integral, using the ASTM standard E-813. This standard utilizes a procedure for estimating the crack initiation point, using a graphical construction and a "crack blunting line". This crack blunting line is given by the following equation:

$$J = 2\sigma_y \Delta a$$

which relates the J-integral with the amount of apparent crack growth, Δa. Here σ_y is the yield stress of the sample. In this expression, the apparent crack growth (as measured visually on the fracture surface) is estimated to be that caused by the "stretch zone", which is given by 50% of the crack tip opening displacement.

Attempts have been made to extend this methodology for ductile (Chan *et al.*, 1983, Hashemi *et al.*, 1986a Narisawa, 1987) or impact-modified polymers (Hashemi, *et al.*, 1986b, Huang, *et al.*, 1987). In recent studies of four impact modified polymers, however, we have made direct measurements of crack growth that conclusively show that the crack blunting concept is invalid for these toughened polymers. It is therefore suggested that a modification to the ASTM standard test protocol be made for impact-modified polymers. The crack blunting line concept should be abandoned (or at least rigorously tested for applicability). In its stead, a direct observation of the crack initiation process should be made by cutting and polishing the sample. This avoids the ambiguity in fracture surface observations that result from extensive plastic deformation, massive voiding or craze damage in the crack tip plastic zone.

EXPERIMENTAL METHOD

For this study, four impact-modified polymers were examined. Two impact-modified blends of poly(butyleneterephthalate) and polycarbonate with different impact-modifier loadings were tested. They will be referred to as PBT/PC(I) and PBT/PC(II), respectively. An ABS (rubber-toughened styrene acrylonitrile copolymer) and a toughened nylon 6/6 (N66) were also studied. 3-point bend bar samples of dimensions 15mm x 123mm x 12.7mm were machined from injection molded plaques. Precracks were machined with a sharpened single-tooth notcher with a tip radius of about 13 microns to create a deep notch, with crack depth to width ratio (a/W) of 0.5.

The R-curve (resistance curve) approach (Begley, *et al.,* 1972) was used for J-integral determination. In this approach, a series of identical samples were loaded to different predetermined loads. After unloading, the samples were analyzed for crack growth by two methods. One half of the sample was used (in the traditional manner) for fracture surface observations. This half was fast fractured after soaking in liquid nitrogen and the apparent crack growth was measured on the fracture surface. The apparent crack growth region is typically identified as the zone between the easily identifiable pre-crack machine notch surface and the characteristic fast-fracture surface. The other half of the sample was polished to produce a side view of the crack near the mid-plane of the sample. After polishing, optical microscopy could be used to observe the crack tip and the associated damage zone ahead, above and below the crack tip. In some cases, these samples were thinned to permit transmission optical microscopy to highlight more features of the crack tip damage zone. A direct, unambiguous determination could then be made of the crack growth.

J-INTEGRAL MEASUREMENTS

For deep notched bend samples, the J-integral can be calculated using:

$$J = 2U/Bb$$

where U is the area under the load-displacement curve, B is the sample width and b is the length of the remaining ligament ahead of the crack. The data for the four impact-modified polymers are shown in the figures. The calculated J-integral values are plotted against both the apparent crack growth as measured on the fracture surface (filled circles) and the directly observed crack growths measured from polished sections and viewed from the side (open circles).

Where a large amount of crack growth occurred (roughly 0.05 mm), both methods of crack growth measurement showed good agreement. These values diverged at lower J-integral values, however. The fracture surface observations produced small, but finite, apparent crack growths, whereas the side-view observations revealed no crack growth. This was seen in all cases except the toughened nylon sample. For this case, the crack growth region could not be distinguished from the fast-fracture surface as they both showed similar surface texture.

Three methods can be used to determine the J-integral fracture toughness at the point of crack initiation. The first, which is the most direct and least ambiguous, is the directly observed value (using the polished side surface observations).

This is given by the intersection of the resistance curve with the y-axis, a value very close to the highest J-value observed with no crack growth.

The second method uses the theoretical crack blunting lines as shown by dashed lines in the figures. According to the ASTM testing protocol, the J-integral fracture toughness is given by the intersection of the crack blunting line with a straight line fit through the resistance curve data (within a specified apparent crack growth range). This produces an overestimate (10-15%).

A third method is to use an experimentally determined crack blunting line instead of the theoretical crack blunting line. Much greater overestimates would result.

DISCUSSION

If our results can be generalized for impact-modified engineering polymers, then we must conclude that the crack blunting concept is probably not appropriate for impact-modified polymers. There are several compelling reasons why this is so. First, fracture surface measurements are often ambiguous. Accurate measurements can only be obtained when clearly distinguishable fracture surfaces are produced which differentiate between pre-notch surfaces, crack growth surfaces and fast-fracture surfaces. This is not always the case, as discovered for the toughened nylon.

Ambiguity can be further compounded when damage zone processes (such as voiding, shear flow or crazing) produce fracture surface texture (stress whitening) that can be mistaken for crack growth. This stress whitening is to impact-modified polymers what "stretch zones" are to ductile polymers. The stretch zones gave rise to the need for crack blunting lines in ductile polymers, and so too, the damage zones necessitated the use of some sort of "crack blunting line" in impact-modified polymers. However, our present results indicate that the crack blunting line concept is not justifiable (at least in its present form).

A final, but perhaps most convincing, argument is that a simple technique, i.e., side-view observations of polished samples, gives accurate, unambiguous determinations of crack initiation.

The crack blunting line concept need not be invoked and a direct evaluation of the J-integral at crack initiation can be made quite accurately.

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