ORAL REFERENCE: ICF100650OR

ON THE APPLICABILITY OF THE ESSENTIAL WORK OF FRACTURE METHOD TO THICK ABS SE(B)-SPECIMENS

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ABSTRACT

This paper deals with the application of the EWF methodology to thick ABS SEN(B)-specimens in order to study its applicability to conditions other than plane stress. Different loading regimes were induced by varying the testing temperature. Post-mortem fracture surface appears to be completely stress whitened, indicating ductile fracture. Load-line displacement plots display geometric similarity over a well-defined range of ligament lengths for which the application of the EWF methodology was in principle possible. At the same time crack growth was observed to initiate before maximum load and the complete ligament yielding. Over a critical ligament length gross yielding occurred and the total specific work of fracture was found independent of ligament length. Below this critical ligament length, EWF methodology seemed to be still applicable and it was possible to extrapolate reliable w_e values. Besides, the EWF was simulated by elastic-plastic FEM analysis. Numerical results were consistent with experimental findings.

KEYWORDS: essential work of fracture (EWF) applicability; ABS; plane stress- plane strain regime; FEM modeling.

INTRODUCTION

The essential work of fracture (EWF) has developed as an efficient methodology to characterize the fracture toughness of ductile polymers films under the plane stress condition[1-4]. At the same time the simplicity of this methodology makes very attractive to extend its applicability to other loading conditions, such us the plane-stress plane-strain transition and pure plane-strain regimes [5-11]. In this sense the present work deals with the application of the EWF methodology to thick ABS SEN(B)-specimens, for which different loading conditions were induced by varying the testing temperature. Experimental results are complemented with numerical FEM simulations.

THE EWF METHODOLOGY

The EWF method is based on the assumption that the total work of fracture, w_f, consists of two work components: one referred to as the essential work of fracture, w_e, which is related to the failure mechanisms that occurs in an inner fracture process zone, and the other referred as the non-essential total work of fracture, w_p, which stands for the work dissipated in the outer plastic deformation zone and is geometry-dependent. To this extent application of the EWF must fulfil the following conditions [4]: (1) the ligament should yield prior to fracture initiation; (2) w_e should be proportional to the ligament length, l; and (3) w_p

should be proportional to the square of the ligament length, l^2. In terms of specific work theory and under a plane stress condition, this leads to the following relationship:

$$w_f = w_e + \beta w_p l \tag{1}$$

in which β is a geometrical shape factor for the outer plastic zone. Consequently, when plane stress conditions prevail for all ligament lengths, it is assumed that w_e is constant and can be obtained by linear extrapolation to zero ligament length. For conditions other than plane stress w_e is not only function of l, but of the specimen thickness B, *i.e.* $w_e=w_e(l,B)$, while βw_p does not depend on l. Under these conditions the essential work of fracture w_{Ie} can be also obtained by a non-linear extrapolation of data to zero ligament length [3].

EXPERIMENTAL PROCEDURE

Experimental set-up

Experiments were conducted on commercial acrylonitrile-butadiene-styrene terpolymer, Lustran ABS-740. Single-notched thick specimens were deformed in bending, SEN(B), as in [7]. Specimen dimensions were: span S=56 mm, width W=13 mm and thickness B as given in Figure 2. A V-notch 1 mm deep was machined at the compression side opposite the sharp notch to avoid hinging. Tests were performed at constant crosshead speed of 2 mm/min (quasi-static loading condition). Different loading regimes were induced by varying temperature (20 and 80°C). As reported in Table 1 yield stress is drastically reduced with the increment in temperature, promoting generalized plastic flow and inducing plane stress condition. The total work of fracture was calculated from the integration of the load vs. displacement data. Finally, and for the sake of simplicity, the EWF was computed by linear extrapolation of data to zero ligament length irrespectively of the stress state [6,8,10].

Experimental results

Fracture surfaces always appeared stress-whitened all over the full ligament. The whitened zones were elliptical, and hence their volumes scaled with the square of the ligament length (see Figure 1). Geometric similarity between specimens of different ligament length were assessed from load-line traces. Only short ligaments did not verify geometric similarity and consequently they were not used for w_e determination. EWF plots are shown in Figure 2, and the obtained w_e values in Table 1.

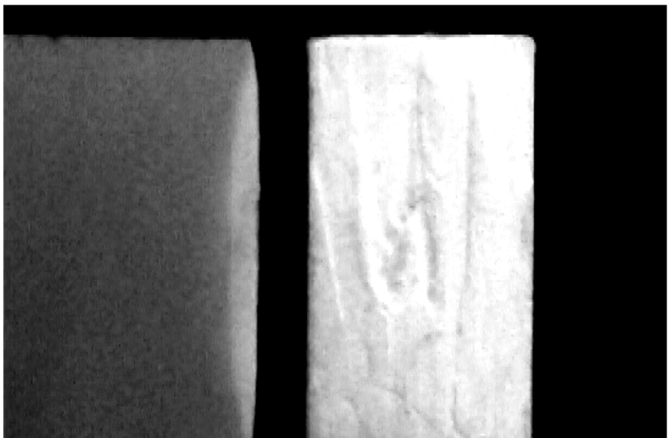

Figure 1: Fracture surface and side view of a broken sample of ABS.

The specific work of fracture was found to be independent of ligament size for long ligament lengths. The same effect was observed by other authors [3,8,12,13]. Among them Lesser and Jones [13] proposed that under this condition the failure mechanism is dominated by gross yielding of the material, and it is not significantly altered by the presence of the flaw. In Figure 2, additional experiments carried out on specimens with blunt starter notches are also shown. The obtained results suggested that the process is not only controlled by the presence of the sharp notch since edge effects are also significant.

TABLE 1

TENSILE YIELD STRENGTH AND SPECIFIC ESSENTIAL WORK OF FRACTURE

	w_{Ie} (N/mm)	σ_y (MPa)
T= 20 ºC, B= 7mm	4.4	42
T= 80 ºC, B= 4mm	6.1	22
T= 80 ºC, B= 7mm	6.3	22

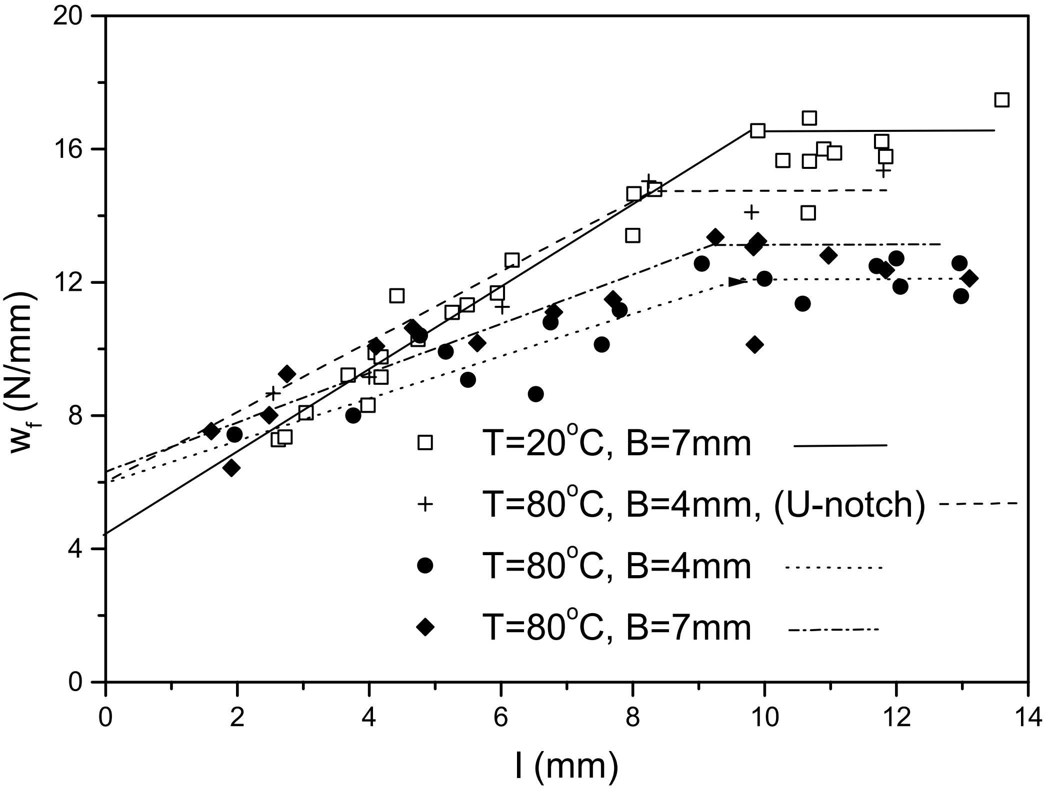

Figure 2: Specific fracture work versus ligament length.

For most of the specimens it was possible to optically check (See Figure 3) that cracks had clearly advanced before the full ligament yields and prior to the attainment of the maximum load. The stress-whitened zone advanced ahead of the crack as it propagated. To achieve the condition of yielding of the full ligament prior to crack propagation seems to be difficult in SEN(B) specimens due to the nature of the bending stress distribution. However, EWF seems to work properly providing that crack propagation occurs after a large plastic zone had developed (see Figure 3).

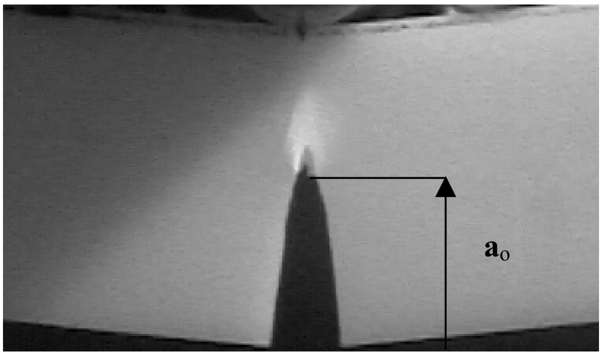

Figure 3: Side view of sample under loading showing that crack initiates before the full ligament yields.

NUMERICAL MODELING

Finite Element Modeling

The EWF was simulated by elastic-plastic FEM analysis by using the ABAQUS program. Crack-tip opening angle (CTOA) was selected as fracture criterion with the "DEBOND" and "FRACTURE CRITERION" options [14]. Two input parameters are needed for the CTOA, i.e. the normal critical displacement between the crack surfaces and the distance behind the current crack tip where the normal displacement is computed. Following the procedure detailed in [15] input parameters were set to 0.3 mm for the distance and 0.21 mm for the normal displacement. Eight-node quadrilateral plane-strain elements were used to discretize one half of the specimen.

Numerical results

Comparison of the numerical load-displacement curves with experimental data for a selection of ligament lengths are plotted in Figure 4 for the room temperature case. The specific work, w_f, is plotted against the initial ligament length in Figure 5.

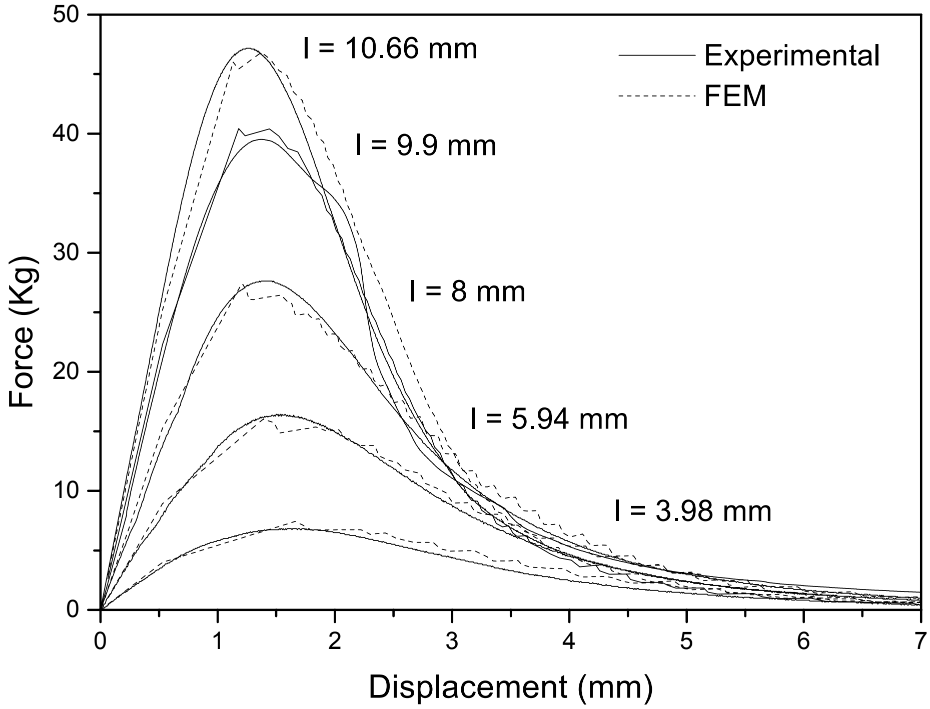

Figure 4: Experimental and numerical P-δ curves for a selection of ligaments

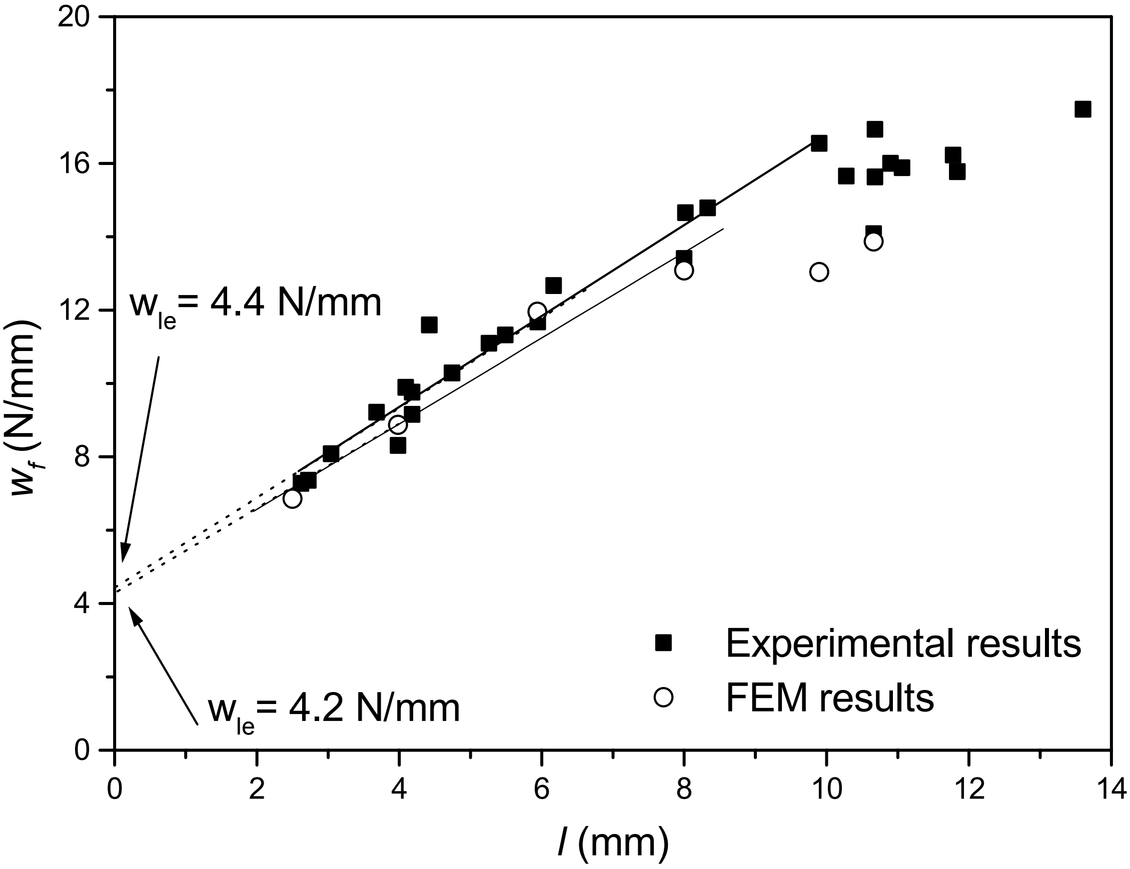

Figure 5: Specific total fracture work versus initial ligament length

Figure 6 shows the deformed configuration at crack initiation, together with the distribution of equivalent plastic strain. It is worth to note that as experimentally observed the numerical model predicts crack propagation before the full ligament yields.

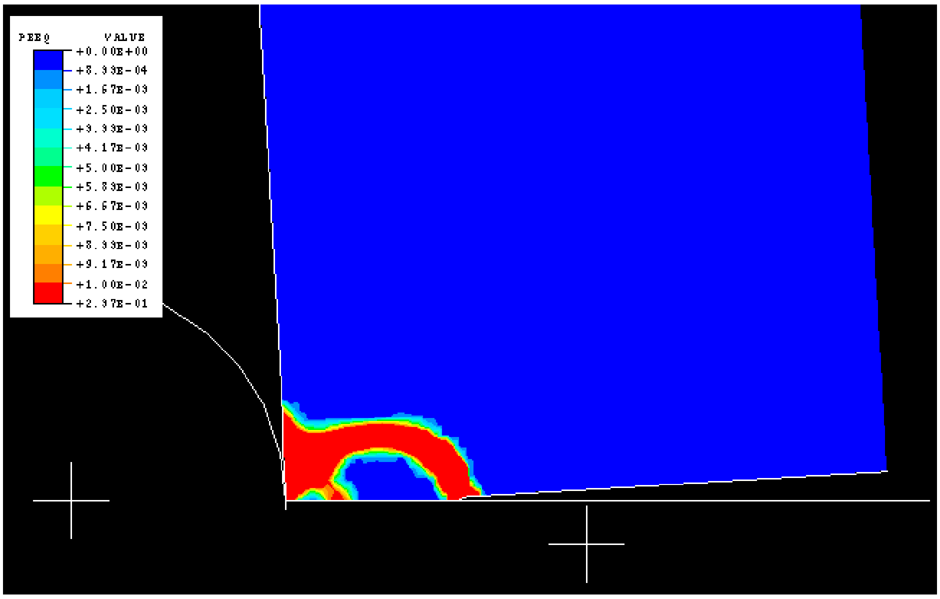

Figure 6: Equivalent plastic strain distribution at the onset of crack initiation

CONCLUSIONS

The EWF was applied to ABS thick specimens at different fracture regimes in bending under static loading conditions. Geometric similarity of the load-line displacement records was verified over a range of ligament lengths for which the extrapolated data led to apparent reliable w_e values. It was observed that in many samples crack growth took place prior the ligament was fully yielded. It seems that this fact does not compromise EWF application, provided a large zone of the ligament is anyway yielded and the stress-whitened zone continues advancing ahead the growing crack. Hence, the requirement for the specimen ligament to be fully yielded before crack propagation appears to be too restrictive for bending experiments.

The total work of fracture was found to be constant over a certain ligament length. These results provide evidence that an upper limit to the methodology validity could exist.

The EWF was successfully simulated numerically using FEM. Results were consistent with experimental findings.

ACKNOWLEDGMENTS

The authors would like to thank the Fundación Antorchas for the financial support of this project between Argentina and Australia.

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