FRACTURE BEHAVIOR OF AN EPBC FILM. STUDY OF THE RELATIONSHIP BETWEEN J0 AND EWF

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ABSTRACT

The fracture behavior for a film of ethylene-propylene block copolymer has been studied applying the essential work of fracture method. Double-Edge Notch Tensile (DDENT) specimens were sharpened by two different techniques. The first technique has been using the conventional method of the razor blade; the second one, using a femtolaser ablation beam. The notch tip radiuses were quite similar. In the case of the razor blade method, some plastic deformation at the crack tip was found. The essential work of fracture (w_e) value for femtolaser sharpened specimens was significantly shorter than for the razor blade sharpening specimens. In this order, the slopes corresponding to the plastic work dissipation factor (βw_p) were quite similar. Results aim to say that the initiation point and the corresponding energy for which w_e is achieved may be considered as the energy of initiation (J_0) for the crack growing propagation. The propagation behavior seems to be the same for both notch sharpening methods. The J_0 value at initiation and w_e were quite similar; the βw_p terms are analyzed from J-R plots.

KEY WORDS: EWF, EPBC film, J_o, fracture initiation.

1. INTRODUCTION

According to the European Structural Integrity Society-Technical Committee 4 (ESIS-TC4) protocol on Essential Work of Fracture (EWF), edited by Clutton [1-3], the energy associated with the fracture process may be separated in two terms; one, We specific to the fracture of the material and, Wp that is related to gross plastic deformation. These two terms according to the ESIS TC-4 protocol are termed essential and non-essential work of fracture respectively. In plane stress, We rises proportionally with the initial ligament length l_0 and the Wp is proportional to the volume of the non-reversible deformation zone. In a pre-cracked specimen with thickness "t" and ligament length "l" (fig. 1), the total work of fracture by surface unit is:

$$w_t = w_e + \beta w_p l \qquad (1)$$

Where βw_p is a factor correlated with the volume of the plastic zone, we is the essential work of fracture and

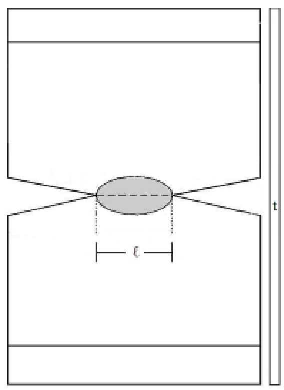

Fig. 1 Double Edge Notched Tension specimen

The here used approach of J is based on the consideration of J as an energy accumulation function, in this way J_i is the Riemann's sum of the load-displacement multiplications from the start of the test to an instant i; divided by the initial measured section of the specimen ($l_0 t_0$), as shown in equation (2).

$$J_i = \frac{1}{l_0 t_0} \sum_{\theta=1}^{i} \left[F \cdot \left(Zc_\theta - Zc_{\theta-1} \right) \right] \qquad (2)$$

2. MATERIALS AND METHODS

The material, an Ethylene-Propylene Bock Copolymer (EPBC), was extruded in sheets of 0.5 mm in thickness, prepared in 90mm x 60 mm DDENT specimens at the machine direction (MD) and sharpened by femtolaser beam and by steel razor blade methods. Some physical properties are shown in table 1.

Table 1 Material characterization

Technique	Property (unit)	Value
RMN	Ethylene Content (% wt)	8.5
ASTM-D638 v = 2 mm/min	σy (MPa)	26.3±0.1
	E (GPa)	1.21±0.01
	Theoretical DDENT σ_m (MPa)	30.3±0.1

The samples was tensile tested at 23°C in the longitudinal axis of the specimen direction, the crosshead displacement rate was stroke controlled at 2 mm/min with a ZWICK-ROELL Amsler HC 25 hydraulic test machine. The instantaneous ligament length was measured with a Digital Image Correlation System ARAMIS, distributed by GOM.

The sharpening methods was carried out as described on [4] for fresh steel razor blade and femtosecond pulsed laser ablation.

3. RESULTS AND DISCUSSIONS

3.1. EWF results

Following the ESIS-TC4 protocol for EWF, there was obtained the values of maximal net stress across a mean of 28.2 ±0.26 MPa for razor specimens as shown in Figure 2; and a mean of 28.7 ±0.73 MPa, Figure 3, for femtolaser specimens.

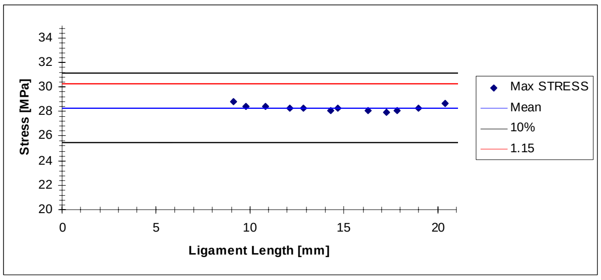

Fig. 2 Maximal stress graph with ±10% of the mean and 1.15 limits for Razor specimens

The regression of the total work of fracture vs. initial ligament length points is shown on Figure 4 for razor and femtolaser specimens.

For razor specimens, the w_e parameter is 164.46 ±9.17 kJ/m^2; and for femtolaser specimens, w_e is 127.05 ±11.58 kJ/m^2. The βw_p factors are 22.55 ±0.61 MJ/m^3 for razor specimens and 21.34 ±0.85 MJ/m^3 for femtolaser specimens.

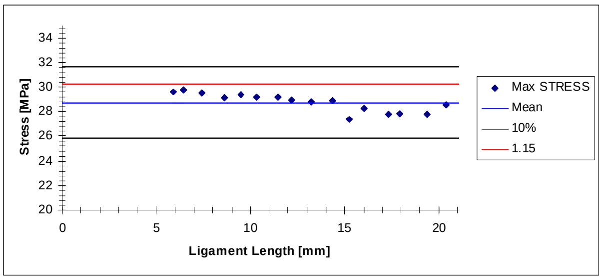

Fig. 3 Maximal stress graph with ±10% of the mean and 1.15 limits for Femtolaser specimens

On the w_e values for both sharpening methods is a difference of almost 40 kJ/m^2. This difference is probably due to the characteristics at the end of the notch tip for each sharpening method. There is an accumulation of material at the notch tip, as reported in [4].

For the βw_p factors there are no longer than 2 MJ/m^3 differences on values. This is because the same region of material is considered in the displacement, as furthered in [5]. It is possible to say that these factors are quite similar, according to Figure 4.

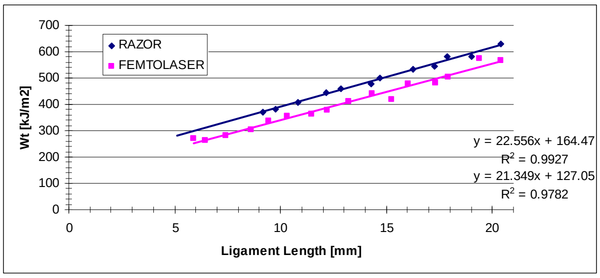

Fig. 4 Comparison between final work of fracture plots for both sharpening method specimens

Finally, for the conventional EWF considerations, it is possible to further that there exist differences on w_e value but not great differences on βw_p for different sharpening methods.

3.2. J results

When energy accumulation described in equation (2) reaches w_e, it is possible to mark a point on the fracture process plot. As well as the area under the curve is equal to w_e, for the specimens from EWF tests, these mark-points are quite similar on displacement.

For different sharpening method, the areas under the curve at w_e are different on displacement values. This aim to say that the phenomena related to this mark-point shows dependence with the sharpening method.

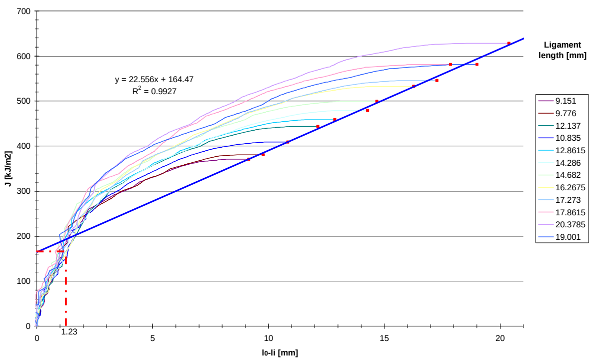

Fig. 5 Accumulated work (J) vs. Δa (l_0-l_i) with final work regression for Razor specimens

It seems that the final behavior, after w_e, for both sharpening methods is similar, there is a resistance to crack propagation. This may be shown because after w_e, the propagation of the fracture keeps the same behavior for both sharpening methods.

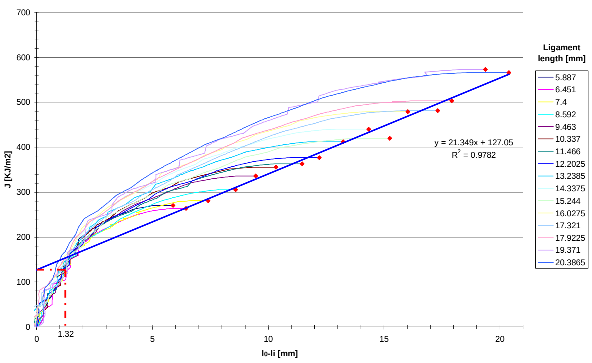

Fig. 6 Accumulated work (J) vs. Δa with final work regression for Femtolaser specimens

In Figures 5 and 6 are plotted the cumulated areas under the curve, energy J in kJ/m^2, for razor and femtolaser specimens respectively. These curves show the behavior or resistance in energy terms to crack propagation, J-R curves.

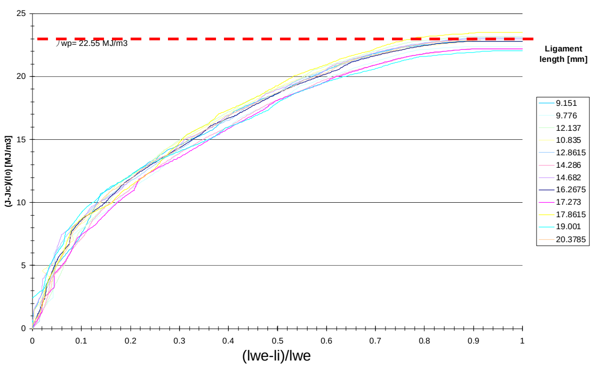

Fig. 7 Normalization of J behavior for Razor specimens

As shown in Figures 5 and 6, the regression of the final work of fracture, final J, and the maximal Δa is congruent to EWF main regression for both specimen series. This is logic because maximal Δa in complete fracture is the initial ligament length and final J is w_t.

A normalization of the behavior is propounded on figures 7 and 8, this is done in the aim to describe the complete crack behavior. On these figures, the end values of the curves are near to βw_p.

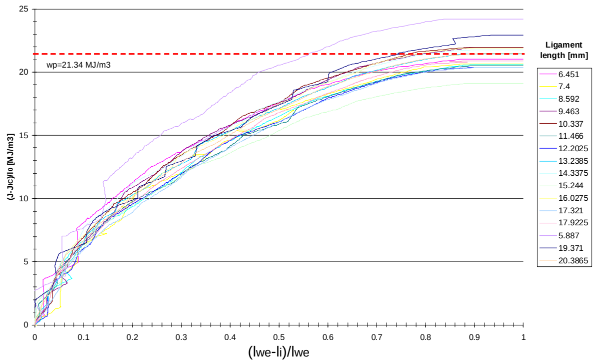

Fig. 8 Normalization of J behavior for Femtolaser specimens

On figure 8, for femtolaser specimens, it is possible to regard scatter in the end values of normalization, this may be attributed to experimental differences.

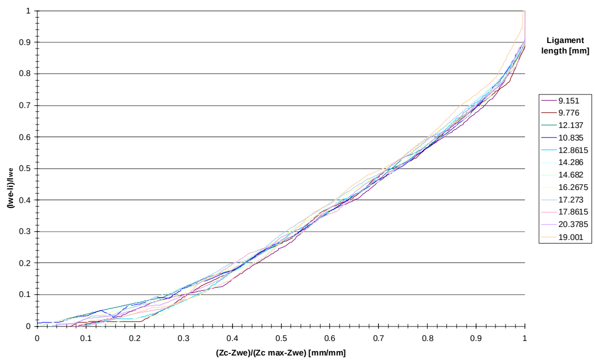

Fig. 9 Normalization of J behavior for Razor specimens

For figures 9 and 10, the crack growth was normalized as a function of the displacement, these figures shown a relative well-similarity for all specimens.

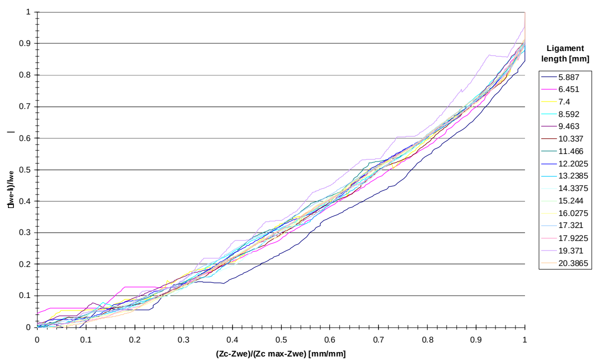

Fig. 10 Normalization of J behavior for Femtolaser specimens

On the crack behavior normalization figures it is possible to see a concordance between curves and even between notch sharpening methods, as shown in figures 11 and 12.

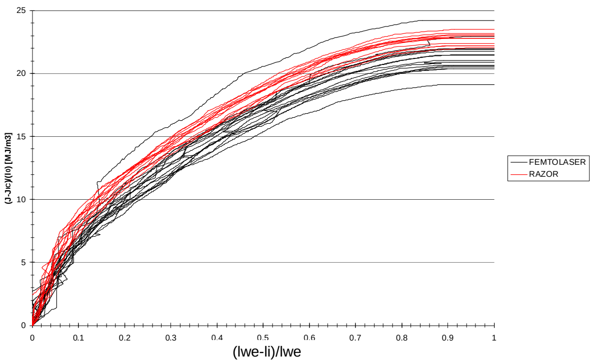

Fig. 11 Notch sharpening comparison on normalization of J behavior

No great difference are shown between notch sharpening methods on here used normalizations, it aims to say that βw_p is a material factor that does not show dependence on the notch tip conditions and that the crack growth of the material may be normalized.

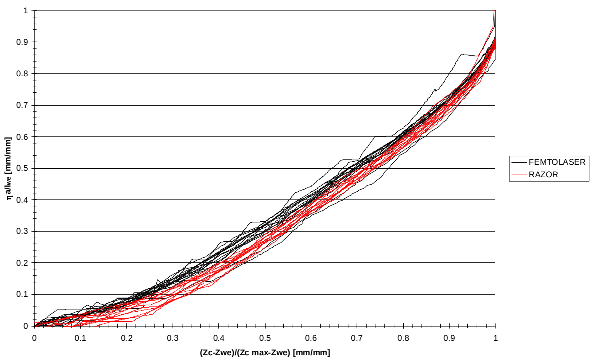

Fig. 12 Notch sharpening comparison on normalization of J behavior

Note that for all the normalizations, the crack behavior starts at w_e, and this value is determined by the EWF method. No before w_e behavior was regarded for normalizations, this behavior (blunting) is only shown on figures 5 and 6.

4. CONCLUSIONS

For the material here studied. The value of J in which the propagation of fracture process starts, J_0, is shown similar or equal to w_e from the EWF test. This value of energy is given as a function of the conditions at the notch tip. The factor of plastic work dissipation βw_p is regarded as a factor that does not shows dependence on the notch tip characteristics. βw_p must be only correlated to the amount of material between distance measurement marks.

It is possible to normalize the fracture behavior after w_e, on energy terms as shown in figures 7 and 8; and on crack growth distance as shown in figures 9 and 10. It aims to say that J is in function of Δa and Δa is in function of displacement. The law for these relationships may be propounded.

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