CHARACTERISATION OF FRACTURE BEHAVIOUR AT LOW STRAIN RATE OF PC/ABS BLENDS.

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In this work we have determined the fracture parameters of PC/ABS blends in the PC-rich range, at low strain rate. It was applied the EPFM J-integral criterion standardised by ASTM and ESIS, and following the Narisawa and Takemori methodology, and compared with the Essential Work of Fracture (EWF) analysis with SENB geometry. It was obtained an excellent correlation between the critical J-value and the EWF critical one. It was observed that the energy required to initiate crack growth increase until 15 % of ABS by weight in the blend, nevertheless, the crack propagation resistance (dJ/da) rise until 20 % of ABS by weight.

INTRODUCTION

The difficult to satisfy the Linear Elastic Fracture Mechanics' (LEFM) size requirements in substantially ductile systems, as in our case, has led to the development of the J-integral analysis proposed by Rice. The experimental procedure to determine the critical J-integral (J_{IC}) – i.e. the minimum energy required to initiate the propagation of a sharp notch – was suggested by Begley and Landes by the construction of the crack growth resistance curve (J-Δa) and the use of the crack-blunting line (1). The procedure for J_{IC} determination has been standardised by ASTM E813 in several versions (E813-81 and E813-89) and for polymeric materials by ESIS in 1991. The major difference between them lies in the determination of acceptable data points for J-Δa curve construction and how to define J_{IC} value, as can be seen in Figure 1.

However, some aspects of these methods still remain controversial, being the most significant the validity of determining crack initiation by the intersection of J-Δa curves and the blunting line as defined with metals. Following the methodology proposed by Narisawa and Takemori (2) a double axis curve could be constructed (Figure 2)

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considering the variation of the crack growth length (Δa) -measured by optical microscopic process zone's side views- and the load reached (P) with the displacement (δ) observed in the point application load. Taking the load (and energy) at which the Δa-δ curve shows an inflection as the initiation of crack propagation, the J-value is determined. This methodology has given good results for PBT/PC blends, ABS, Nylon 66 (2) and PS/SBS blends (3).

As an alternative to J-integral analysis, it has been proposed (4) the use of the Essential Work of Fracture (EWF) analysis in Single edged notch in bending (SENB) geometry. This analysis, based on the Broeberg's idea, sets that the *Total Work of Fracture* (W_f) is the sum of an *Essential Work* component (W_e) dissipated in the formation, deformation and rupture of the zone preceding the crack, and a *Non-essential* component (W_{ne}) dissipated in the external zone which depends on the volume of the necked zone. Thus, the specific total work of fracture (w_f) can be expressed as:

$$w_f = w_e + \beta w_p (w - a) \qquad (1)$$

where w_e and w_p are the Essential Work of Fracture per unit of ligament length and the Non-essential or Plastic Work per volume unit respectively. β is a shape factor that describes the plastic zone size. B, w and a are the specimen thickness, width and initial crack length, respectively. Based on the similar sense of the vectorial equation components postulated by Rice for the J-integral definition and that for the Eq. 1, it has been suggested a "term by term" comparison, thus J_{IC} could be considered equivalent to w_e, situation that was confirmed for PC/PBT blends (4).

The aim of the work reported here was the quantitative evaluation of PC/ABS blend's fracture at room temperature and a strain rate of 0.3 min^{-1} (cross head speed: 1 mm/min), applying the J_{IC} methods' and the EWF in SENB geometry.

EXPERIMENTAL

Blends were prepared in an injection machine using 5, 10, 15, 20, 40 and 100 % of ABS by weight, and with the temperature and pressure conditions reported previously (5). All the tests were carried out on prismastics bars (6 x 13 x 60 mm) in an instrumented universal testing machine in bending configuration with a span of 50.8 mm. The J-Δa curves was constructed by multiple SENB specimens (at least 15) methodology with a normalised crack length (a/w) of 0.5. The EWF tests were made with at least 14 specimens varying a/w from 0.27 to 0.57. From the Load (P) vs. displacement (δ) curves the maximum load ($P_{máx}$), its respective energy consumption ($U_{máx}$) and the total energy (U_T) were taken.

RESULTS AND DISCUSSIONS

As an initial step, the stress and deformation fields were analysed by the Slip Line field theory (6). In this case, considering the geometric relationships, action/reaction force and momentum balances, the P_{max} reached in bending tests of SENB sharp notched specimens could be related with the flow stress (σ_f), determined in unidirectional tensile tests, by:

$$P_{máx} = \gamma\sigma_f (w - a)^2 \qquad (2)$$

$$\gamma\sigma_y = 2fBk / S \qquad (3)$$

where f is the relation between the bending moments of a non-notched specimen and a notched one (1,26 in our case). k is the pure shear yield stress and S the span. Following the Tresca yielding criterion (σ_f=2k), γ is 0.1488 only if the crack propagation begins after the system's plastic collapse (3).

The EWF analysis requires that w_e, w_p and β be independent on ligament length, situation reached if a uniform and unique stress state is generated. In this case, the deformation zone area (A_{zd}) – i.e. the ellipsoidal whitening zone generated ahead the crack – follows the relation (7):

$$Log(A_{zd}) = Log(\beta) + 2Log(w - a) \qquad (4)$$

The experimental data from variable a/w tests shows an excellent fit to eqs. 2 and 4 (Table 1). This situation lets establish that before the beginning of crack propagation, the ligament length reach an extensive yield (proximity of γ to the theorical value) and, by the other side, that the deformation and stress' fields are almost constant in the ligament range analysed for the EWF tests (Eq. 1's fitting slope near 2).

TABLE 1- Fitting parameters obtained for equations 2 and 4. σ_f : Flow (neck propagation) stress. r^2: correlation coefficients.

ABS %-w	Slope (Eq.1)	r^2 (Eq. 1)	β	Slope (Eq.2)	r^2 (Eq. 2)	σ_f (MPa)	γ
5	1.919	0.9813	0.3170	6.5539	0.9906	46.7	0.1403
10	2.036	0.9617	0.2549	6.6742	0.9929	46.4	0.1438
15	2.034	0.9930	0.2261	6.7012	0.9954	46.0	0.1457
20	2.060	0.9952	0.2252	6.4584	0.9978	45.3	0.1426
40	2.088	0.9626	0.2249	5.6574	0.9968	43.5	0.1301
100	1.977	0.9346	0.1648	4.0299	0.9963	31.2	0.1292

Table 2 shows the J-integral characteristics values applying the standards mentioned in the introduction. In order to distinguish between the parameters obtained, it has been set the following notation: J_{IC-81} and J_{IC-91} are the J_{IC} values using the crack blunting line with the exclusion criteria set in ASTM E813-81 and ESIS 1991, respectively (Figure 1). J_{0-81} is the intercept with Y-axis of the valid points linear fitting in the J-Δa curve for

ASTM E813-81. $J_{0\text{-}cp}$ is the value calculated from the "pattern curve" methodology (Figure 3). All of the J-values satisfy J-controlled crack growth dimension conditions – i.e. B, (w-a), a > 25(J-value/σ_y).

Analysing the results, it could be considered as the most realistic the $J_{0\text{-}cp}$ since its evaluation imply the onset crack propagation, i.e. determinations of crack propagation below the exclusion line sets in the standards, and not from the fitting of the propagated data. The $J_{IC\text{-}81}$ values seem to be nearer to those determined by the "pattern curves" almost for low ABS contents in the blend. The $J_{IC\text{-}91}$ values have no sense since they represent load values for the onset crack propagation in the lineal P-δ range, which would imply a satisfactory LEFM application, nevertheless this analysis was rejected since the $P_{5\%}/P_{máx} < 1.1$ criterion, proposed in the EGF 1990's protocol, was no satisfied.

Table 2 also shows the w_e and w_p parameters of the EWF analysis. As can be seen, the w_e and the $J_{0\text{-}cp}$ are very approximate and dJ/da and w_p showed the same behaviour, thus, the relationships proposed between the EWF concept and J-integral are corrects and applicable to this geometry and blends.

TABLE 2: Fracture parameters obtained by J-integral and EWF analysis.

ABS %-w	$J_{IC\text{-}81}$ (kJ/m^2)	$J_{0\text{-}81}$ (kJ/m^2)	$J_{IC\text{-}91}$ (kJ/m^2)	$J_{0\text{-}cp}$ (kJ/m^2)	dJ/da (kJ/m^{2}mm)	w_e (kJ/m^2)	w_p (kJ/m^{2}mm)	B,a, (w-a) (mm)
5	5.81	5.36	4.07	5.55	10.136	5.53	7.97	2.18
10	5.72	5.38	4.74	6.75	13.628	6.75	10.15	3.06
15	6.14	5.49	4.40	7.21	14.581	7.26	10.7	3.46
20	4.57	4.06	2.16	6.65	14.890	5.80	11.12	3.14
40	2.87	2.54	1.29	3.70	14.519	3.69	9.90	1.86
100	2.70	2.35	0.91	2.95	12.059	2.97	9.70	2.16

The parameters' behaviour (Figure 3) in the range blend compositions studied, excepting $J_{IC\text{-}91}$, , showed an increase in the critical energy for crack propagation until an ABS 15% by weight. The ABS reinforcing effects seems to lose effectiveness when its reaches 40% by weight in the blend where a drop of the value under the expected limits is seen. While between 15 and 20 %-w of ABS there is a decrease on the energy consumed for crack initiation, a Non-essential work of fracture (w_p) increase is observed. It could be related with an increase of the value dJ/da – taken as the slope of the linear fitting of valid points as ASTM E813-81 describe - associated to the propagation resistance of the crack as Lee and Chang sets (8). Both observations reveal a higher work for crack propagation rather than initiation concerning this composition.

Making a morphological analysis by SEM techniques in cryogenic fracture surfaces parallel and transverse to the flow direction in the moulding cavity, it was stated that from ABS 15 %-w, there is a morphological gradient characterised by uniform and isolated domains in the central section, while in the surface exist a high orientation degree, markedly in the blends with 20 %-w of ABS (9). In the ABS 40 %-w blend composition there is a highly co-continuous and stratified morphology over all the specimen section, promoting the loss in the reinforcing effectiveness by the deformation mechanisms involved in the fracture process.

CONCLUSIONS

Almost for the blends compositions analysed in this work, seems to be more adequate the use of the methodology proposed by Narisawa and Takemori to determine the J-integral value at the onset of crack propagation.

The EWF analysis in SENB specimens is valid only if the stress state is unique at the ligament length range studied, monitored by the adjustment to the "Slip line theory" and the necked zone dependence with the ligament length. Thus, it is offered as an alternative way of evaluating crack propagation parameters where the J_{IC} criteria present technical difficulties of evaluation.

A global analysis of ductile systems, as our blends, requires consider the critical energy value for crack initiation and the propagation resistance that the material offers.

The ABS content action in PC/ABS, offers its maximum effectiveness, referring to the energy for crack propagation until 15 %-w. From here the behaviour is governed by the morphological conditions reached during the moulding.

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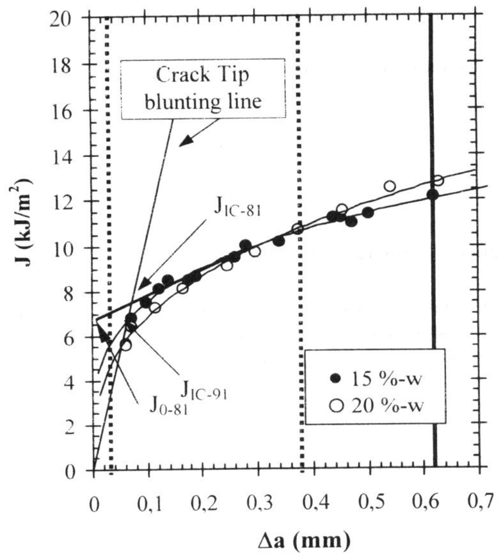

Figure 1. J-Δa curves following the exclusion lines criteria sets by ASTM E813-81 -0.6 % and 6 % of (w-a)- (----) and ESIS in 1991 -10 % of (w-a)- (——).

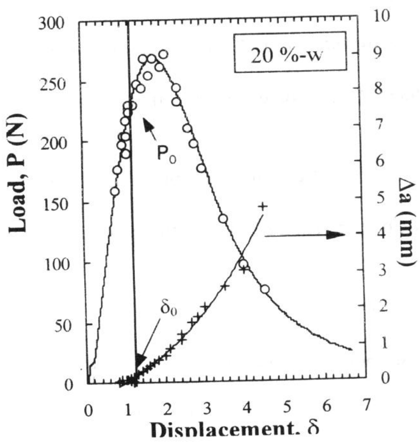

Figure 2 "Pattern Curve" example.

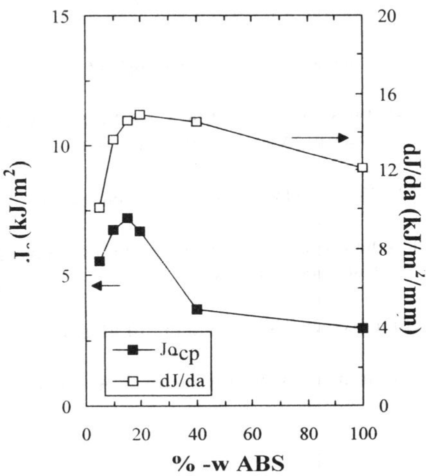

Figure 3 Fracture parameters variation with blend composition