A FRACTURE MECHANICS METHODOLOGY FOR PREVENTING RAPID CRACK PROPAGATION IN POLYETHYLENE PIPES

F.Massa*, A. Laurent* and R. Piques*

The evolution of the crack initiation toughness taking into account only the temperature parameter is not satisfactory for materials like high density polyethylene. The identification of a shift factor as a function of the temperature based on uniaxial tensile tests enables the introduction of a new parameter combining time and temperature. Two geometries are tested at different strain rate and temperature for the validation of this new criterion for the rapid crack initiation fracture toughness.

INTRODUCTION

Most semi-crystalline polymers display considerable ductility at room temperature. Nevertheless, in these materials a brittle failure easily occurs under low temperature or high strain rate conditions without large scale yielding. To calculate rapid crack fracture toughness, linear fracture mechanics may be applicable by using parameters like K_{IC} or G_{IC}. The previous attempt to propose criteria based only on temperature dependence $K_{IC}(T)$ (e.g.Chang and Williams (1)) is not satisfactory for most semi-crystalline thermoplastic materials. The identification of a shift factor a_T calculated from an experimental study of the yield stress σ_s as a function of the temperature T and strain rate $\dot{\varepsilon}$ enables the introduction of the parameter $a_T\dot{\varepsilon}$ to plot the master curve giving the fracture toughness as $K_{IC} = f(1/a_T\dot{\varepsilon})$ or $G_{IC} = f(1/a_T\dot{\varepsilon})$. A critical value $(a_T\dot{\varepsilon})_c$ is proposed to limit the validity of such a curve.

EXPERIMENTAL PROCEDURES

Since the process zone ahead the crack tip depends on the yield stress σ_s, the shift factor a_T (figure 2) is determined to perform the superposition of σ_s versus strain rate $\dot{\varepsilon}$ curves (figure 1). These curves are ploted by testing tensile specimens in a wide range of temperature [-50°C,+60°C].

*Ecole des Mines de Paris - Centre des Matériaux URA CNRS n° 866 BP 87
F-91003 Evry Cedex, Fax 33 1 60 76 31 60

Rapid crack propagation tests are carried out either on cracked ring specimens (figure 3) tested in compression or on Charpy specimens (figure 4). Each geometry is tested on different strain rate range, respectively $\dot{\varepsilon} \approx 0.015\ s^{-1}$ and $\dot{\varepsilon} \approx 50\ s^{-1}$; the temperature range is [-100°C, +20°C]. The loading is measured in order to calculate the rapid crack fracture toughness (K_{IC} or G_{IC}) according to references (Massa (2) and (3)). The details of the experimental procedures are given elsewhere (Massa (2)).

RESULTS AND DISCUSSION

The investigated material is a high density polyethylene used to extrude pipes for gas distribution.

The crack initiation fracture toughness $K_{IC}(1/a_T\dot{\varepsilon})$ curve of the ring test ($\dot{\varepsilon} \approx 0.015\ s^{-1}$) decreases continiously (figure 5). Even though in the Charpy tests, the strain rate is about 3300 times higher than in the ring tests, the $K_{IC}(1/a_T\dot{\varepsilon})$ Charpy also is decreasing (figure 6). Above the critical value $(1/a_T\dot{\varepsilon})_c = 422$ s, the linear fracture mechanics are no longer valid. This is related to the loss of constraint of the crack tip process zone.

The critical energy (G_{Ic}) applied to characterise the brittle fracture initiation increases in many cases when the temperature increases. The former experimental results dealing with high density polyethylenes (1) show a decrease of $K_{IC}(T)$. The evolution of the elastic modulus E in a polyethylene studied by F.Massa in his thesis (2) (see figure 7) enables to explain this observation. There is a very important evolution for the elastic modulus between -100°C and +20 °C with a scale factor greater than 5. With the relationship K # $(EG)^{1/2}$, it is possible to observe an increasing variation of G_{IC} related to a decreasing effect for K_{IC}. The diagram G_{Ic} versus $1/a_T\dot{\varepsilon}$ (figure 8) presents the results dealing with both ring and Charpy cracked tests. Therefore, we can consider that the suitable parameter to predict the initiation of a rapid crack propagation in high density polyethylenes is the G_{IC} parameter.

Further, the introduction of the $a_T\dot{\varepsilon}$ parameter enables the plot of an appropriate fracture toughness master curve G_{IC} versus $(1/ a_T\dot{\varepsilon})$ (figure 8). We can calculate an unique and characteristic transition value $(a_T\dot{\varepsilon})_c$ for the investigated high density polyethylene. Above $\log(1/a_T\dot{\varepsilon})_c = 2.62$, the linear fracture mechanics are no longer valid.

CONCLUSIONS

The introduction of the $a_T\dot{\varepsilon}$ parameter enables the plot of an appropriate fracture toughness master curve G_{IC} versus $(1/a_T\dot{\varepsilon})$ to predict the initiation of rapid crack propagation regimes in a wide range of temperature and strain rates.

An unique and characteristic value is proposed to limit the validity of such a curve for the investigated high density polyethylene: $(1/a_T\dot{\varepsilon})_c = 422$ s .

ACKNOWLEDGEMENTS

Financial support from Gaz de France (GDF) is gratefully acknowledged.

REFERENCES

(1)Chang, M.K.V.and Williams,J.G., Int. J. of fracture, Vol. 23, 1983, pp.145-159.
(2)Massa, F., Nocivité des fissures dans le polyéthylène. Critères de rupture, Thesis, Ecole des Mines de Paris, 1995.
(3)ESIS, Testing Protocol, LEFM Standard for Determining K_{IC} and G_{IC} for plastics, March 1990.

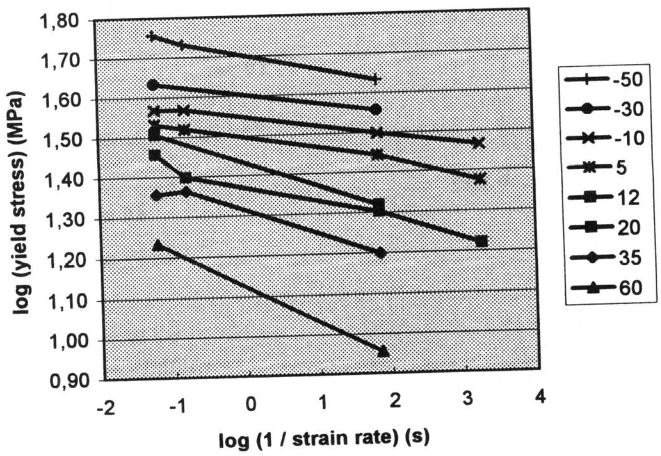


Figure 1 : Logarithmic plot of the yield stress σ_s versus $1/\dot{\varepsilon}$.

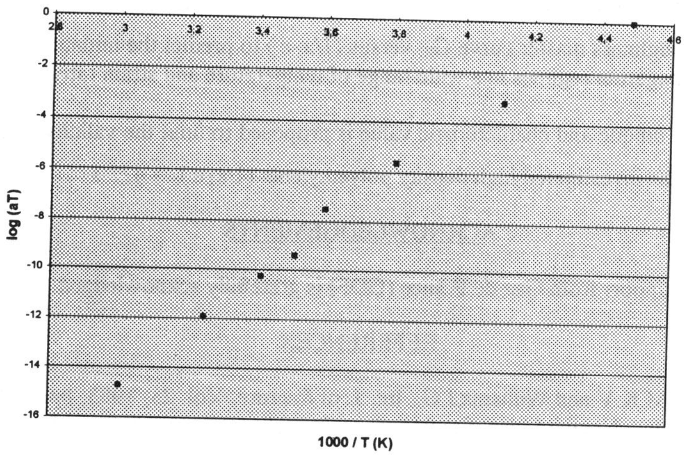
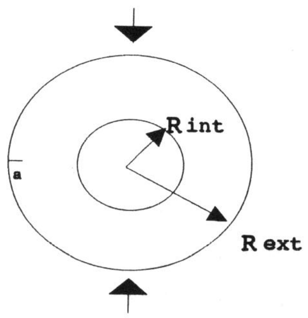
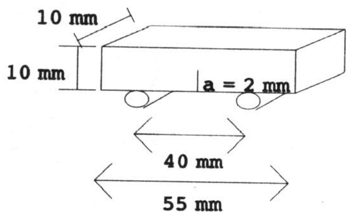


Figure 2 : Semi-logarithmic plot of the shift factor a_T versus 1000/T(K).



$\beta = R_{int} / R_{ext} = ½$
$\lambda = a / (R_{ext}-R_{int})$
R_{ext} = 50 mm, B = thickness =15 mm

figure 3 : Ring specimen



a / W = 0.2
width W = 10 mm
B = thickness = 10 mm

figure 4 : Charpy specimen

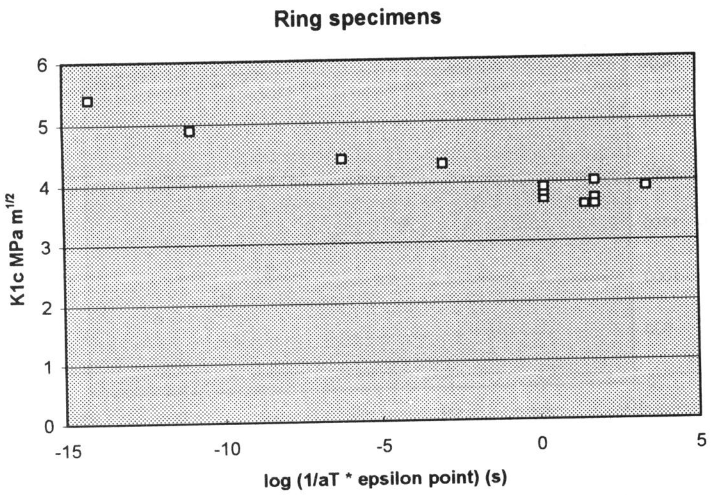


Figure 5 : Fracture toughness K_{Ic} versus $\log(1/a_T \dot{\varepsilon})$

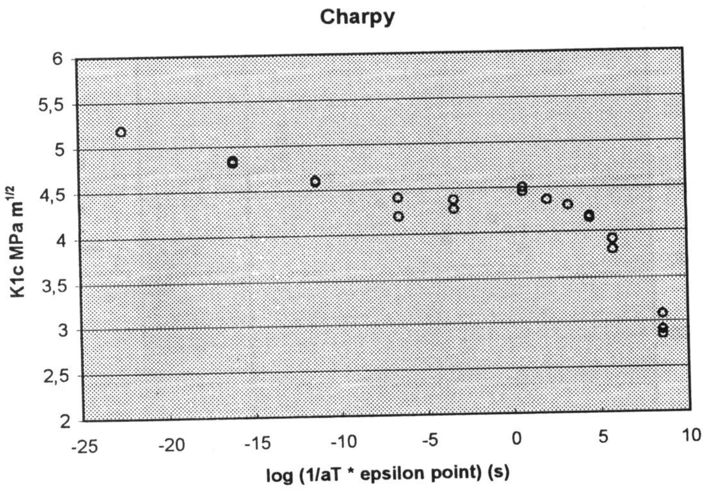


Figure 6 : Fracture toughness K_{Ic} versus $\log(1/a_T \dot{\varepsilon})$

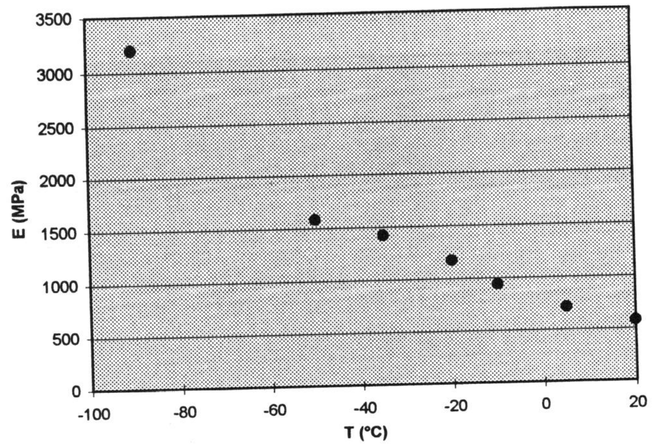


Figure 7 : Elastic modulus versus temperature

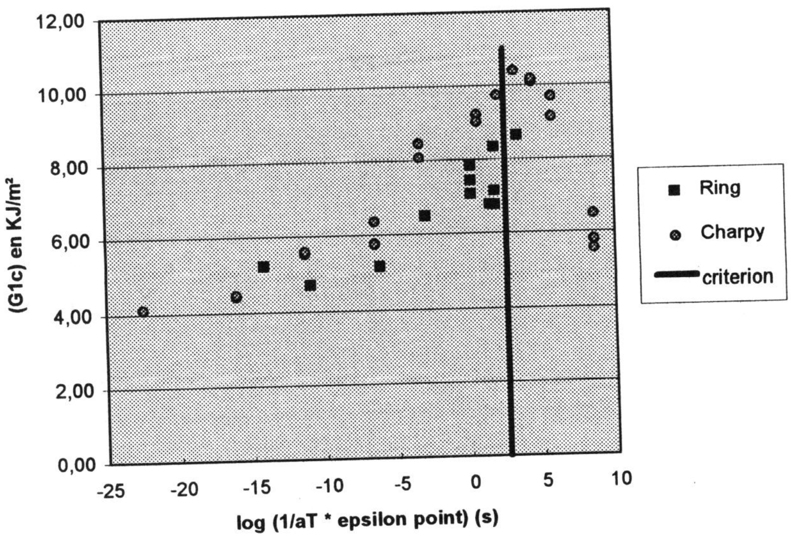


Figure 8 : Fracture toughness master curve G_{IC} versus $\log(1/a_T \dot{\varepsilon})$