A comparison between K and G approaches for a viscoelastic material: the case of environmental stress cracking of HDPE

M. Contino[a], V. La Valle[a], L. Andena[a], M. Rink[a], G. Marra[b], S. Resta[b]

[a] Politecnico di Milano, Italy,
(marco.contino@polimi.it, vincenzo.lavalle@mail.polimi.it, luca.andena@polimi.it, marta.rink@polimi.it)
[b] Fater S.p.A., Italy
(marra.g@fatergroup.com, resta.s@fatergroup.com)

Keywords: environmental stress cracking, hdpe, fracture mechanics

Introduction

For a linear elastic material the plane-strain energy release rate G can be evaluated from the applied stress intensity factor K and the material Young's modulus E and Poisson's ratio ν according to:

$$G = \frac{K^2(1 - \nu^2)}{E} \tag{1}$$

Introducing the time-dependent properties $K(t)$, $\nu(t)$ and $E(t)$, Eq.1 has been adapted to the case of linear viscoelastic materials, as in [1,2]. Even if this approach is commonly used also for highly nonlinear polymers, its accuracy in this case is still an open question.

During this work the validity of this approach was verified for a high density polyethylene (HDPE) tested both in air and in solutions known to promote Environmental Stress Cracking (ESC).

Objectives and Methodology

The fracture behavior at 60°C of a blow molding HDPE grade (HDPE MONO in [3,4]) was characterized applying, thanks to custom-built testing machines, a constant load to Single Edge Notched Bending specimens in four point bending configuration. Tests were conducted both in air and in the presence of an aqueous solution containing sodium hydroxide, sodium carbonate, perfumes and surfactants.

To verify if the expected correlation between K, G and E holds in the present case, the energy release rate was evaluated for the initiation and propagation phases of fracture using the formula:

$$G = \frac{U}{B \cdot W \cdot \phi\left(\frac{a}{W}\right)} \tag{2}$$

in which U is the external energy absorbed by the specimen during the fracture process, B and W are the specimen thickness and width respectively, a is the crack length and $\phi\left(\frac{a}{W}\right)$ is the energy calibration factor for the considered test configuration. Knowing the values of K (from [3,4]) and G, it was hence possible to back-calculate an effective E at any time during the fracture test.

From the measured specimen deflection u the strain level during the various tests could be determined as:

$$\varepsilon = 4.36 \cdot u \cdot \frac{H}{L^2} \tag{3}$$

in which H was taken as the ligament length $(W - a)$, and L is the span length.

The minimum and the maximum strain levels reached during all the tests were considered as lower and upper bounds and the relaxation modulus in these two conditions was evaluated from the stress-strain curves obtained from tensile tests on the same material. These results were finally compared with those obtained from the fracture tests to verify the validity of equation (1).

Results and analysis

The initiation ($\log G$ vs. $\log t_i$) and propagation ($\log G$ vs. $\log \dot{a}$) behavior of the considered material is reported in Fig. 1. As expected, above a certain critical interaction time t_i^* and below a critical crack speed $\dot{a}^*$ fracture occurs faster in presence of the active environment while a unique G^* can be defined as ESC parameter. These results are in agreement with those reported in [4] for the same material in terms of stress intensity factor.
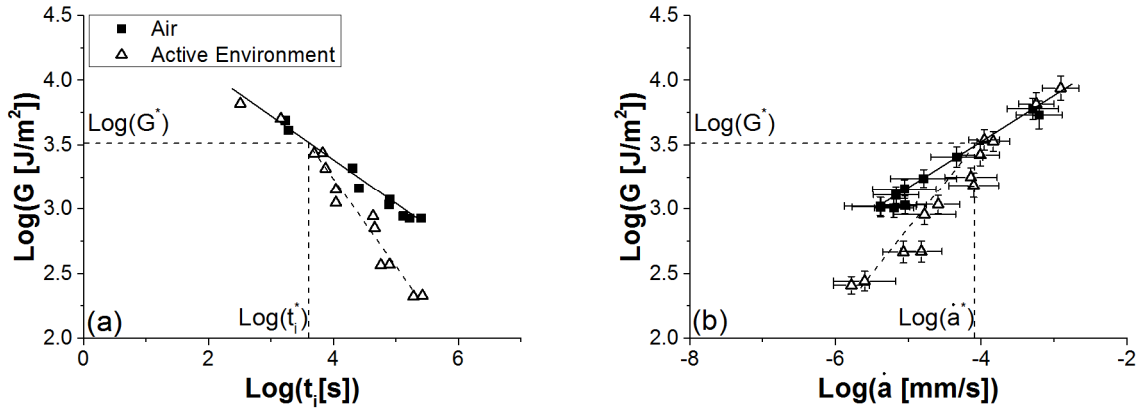

Fig. 1: Fracture behavior at 60°C. (a) initiation ; (b) propagation.

The modulus determined from Eq. (1) is reported in Fig. 2. It is possible to observe that values lie between the two straight lines corresponding to the relaxation modulus, from tensile tests, at the minimum and maximum tensile strain achieved during fracture tests. Therefore Eq. (1) seems to be still valid in this case and it could be used to evaluate G from K, provided that the average strain during the fracture test is known.
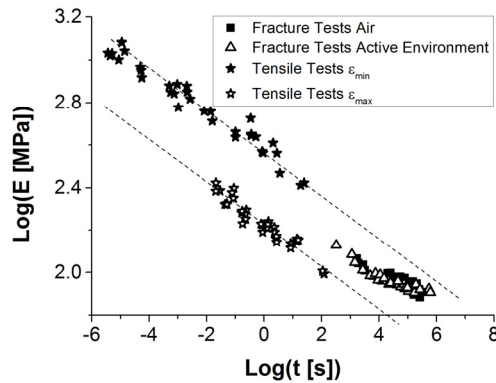

Fig. 2: Comparison between the relaxation modulus from tensile and fracture tests.

References

[1] Schapery R.A. A theory of crack initiation and growth in viscoelastic media. I. Theoretical development. *International Journal of Fracture*, 11:141–59, 1975.

[2] Williams J.G. *Applications of linear fracture mechanics*. In *Advances in polymer science* 27:67–120, 1978.

[3] M. Contino, A. Colombo, L. Andena, M. Rink and G. Marra, Fracture of high-density polyethylene for bleach bottles. *Procedia Structural Integrity*, 2: 213-220, 2016.

[4] M. Contino, L. Andena, M. Rink, G. Marra, S. Resta. Time-temperature equivalence in environmental stress cracking of high-density polyethylene. *Engineering Fracture Mechanics*, submitted paper.