FRACTURE CHARACTERIZATION OF DUCTILE POLYMERS: RECENT APPLICATIONS OF THE LOAD SEPARATION CRITERION

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Abstract

For ductile polymers, the development of sound relationships between material structure and fracture response calls for the use of robust testing methodologies able to measure properties that describe the different processes occurring during fracture. The most common testing methods used with these materials appear inadequate, and there is a need to examine new approaches. This paper describes the most recent applications of the load separation criterion (LSC) in the fracture characterization of ductile polymers: the testing procedures are introduced and some representative results shown.

1. Introduction

The fracture behavior of ductile polymers (in mode I, under plane-strain conditions) is inherently complex. A pronounced crack blunting, coupled with extended plastically deformed zones, is typically observed. Assuming that a fracture initiation concept is still valid, this is not a blunting-to-fracture abrupt transition but rather a progressive process. Further, material viscoelasticity adds another degree of complexity. For the fracture characterization, LEFM approaches cannot be successfully used. Even the most common testing methods developed within the frame of EPFM, based on J-integral, often do not produce reliable results due to the uncertainties associated with the measurement of crack growth and the identification of an initiation point. This pushed towards the research of new testing schemes, and the possible use of the LSC has been examined. LSC assumes that during a fracture test on a cracked specimen, in the plastic region, the load can be expressed as the product of two independent functions: the G function, which depends only on the geometry (including the crack length), and the H function, which is the material plastic deformation function. ESIS TC4, which is the Technical Committee 4, "Polymers, Polymer Composites and Adhesives," of the European Structural Integrity Society, ESIS, of which the authors are active members, has been working on the applicability of the LSC in J-testing of ductile polymers since 2010[1], and a reference testing protocol (LSC-protocol hereinafter) was developed[2]. The testing method described in this protocol requires, in principles, the execution of only two tests: on a sharp-notched (sN) and on a blunt-notched (bN) specimen. From the elaboration of the loading curves, a load separation parameter curve (R_S curve) is constructed, and two parameters are determined: $J_{I,lim}$, which is the value of J-integral at fracture initiation (it is the material J_{Ic} if the size criteria proposed for critical J-values are fulfilled), and m_S, which is a specimen characteristic and provides an indication of the crack advancement produced per unit of u_{pl} (u_{pl} is the non-elastic component of the displacement). The function H is also of great help for the understanding of the fracture behavior of these materials[3]. Easily determinable from a bN specimen test, it provides a local description of the material plastic deformation response during fracture. Related to the constraint level raised by the notch (under fully plastic conditions), it can be used to explain specimen geometry effects as well as to investigate the deformation mechanisms involved in the fracture process. This paper describes how the concurrent use of ESIS TC4 LSC-protocol and H function can provide a valid support in the fracture characterization of ductile polymers in view of the development of structure-property relationships.

2. Results

The results obtained from the application of the LSC-protocol to several ductile polymers (four different rubber-toughened, RT, polymers and a linear low-density polyethylene, LLDPE) are reported in Figure 1 and Table 1. The RT polymers examined are: an acrylonitrile-butadiene-styrene (ABS), a high-impact polystyrene (HIPS), a RT-polybutylene terephthalate (RT-PBT) and a RT-polyamide 66 (RT-PA66) in slightly wet conditions. Tests were carried out at low rate and room temperature, on single-edge notched in bending specimens obtained from bars cut out from injection-molded ISO dumbbells for the RT polymers (with nominal thickness, B, of 4 mm and width, W, of 10 mm), and from 10 mm thick injection molded plates for the LLDPE (B = 10 mm, W = 20 mm). The LSC-protocol outputs are represented both as R_S curves, and as $J_{I,lim}$ and m_S data. For each material, with the only exception of LLDPE, the blunting phase is easily separated from the fracture propagation phase and the initiation toughness, J_{Ic}, determined (ABS shows the highest value of J_{Ic}, HIPS the lowest). It also emerges that the response of LLDPE specimen is governed by blunting (very low m_S), whereas HIPS specimen results the most inclined to exhibit crack growth in the plastic region. Figure 1 also shows the H functions of the various materials, here represented in a dimensionless form[3], as L *vs* u_{pl} curves. The differences among the plastic deformation responses of the various materials emerge clearly, with the LLDPE curve that keeps below the others for low values of u_{pl}, and shows a more stable trend (characterized by the lowest variation of its derivative). LLDPE results the material with the highest "ductility". Further applications of the H functions will be shown in the talk.

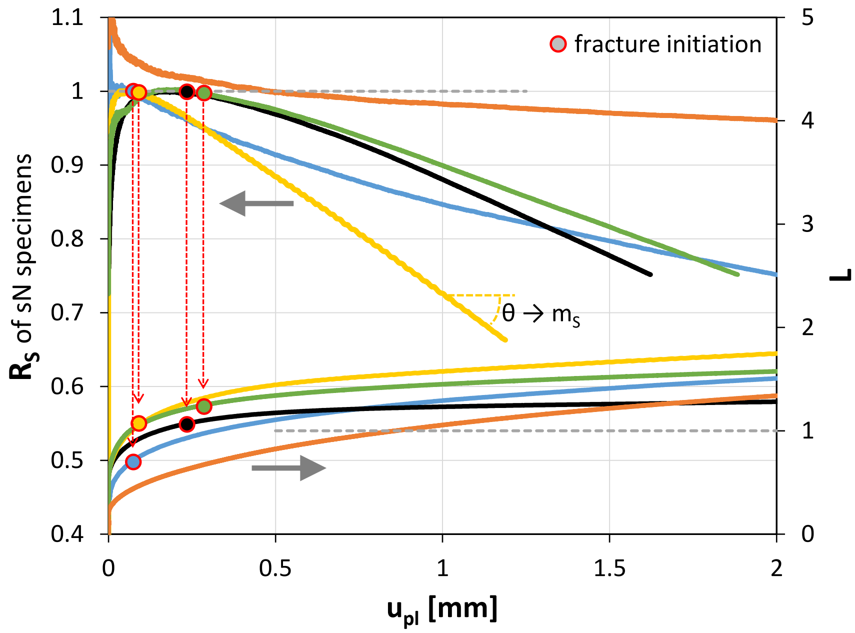

Fig.1 – R_S (left axis) and L (right axis) curves obtained from the fracture tests on the materials of Table 1.

Tab. 1 – Tensile (Young's modulus, E, and yield stress, σ_y) and fracture properties of the materials.

Material	**Tensile properties**		**Fracture properties**	
	E [GPa]	**σ_y [MPa]**	**$J_{I,lim}$ (J_{Ic}) [kJ/m^2]**	**m_S[a] [mm^{-1}]**
HIPS	1.76	18	1.2	0.321
RT-PA66	0.94	31	3.0	0.090
RT-PBT	1.45	31	4.3	0.166
ABS	2.20	46	4.7	0.209
LLDPE	0.25	8	-[b]	0.019

[a]: specimen characteristic; [b]: fracture initiation not detected.

3. Conclusions

The testing schemes based on the LSC can effectively give some valuable insights into the fracture of ductile polymers, even overcoming the limitations that more common EPFM approaches (first of all, the J_R curve multi-specimen method) show when applied to these particular materials.

References

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2. S. Agnelli and F. Baldi, "A testing protocol for the construction of the load separation parameter curve for plastics", ESIS TC4 Communication (2015)
3. S. Agnelli et al., *Mechanics of Materials* 117 (2018) 105-115