Effects of Thickness, Deformation Rate and Energy Partitioning on the Work of Fracture Parameters of uPVC Films

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Summary
Unplasticised poly(vinyl chloride) (uPVC) films have been tested using the essential work of fracture (EWF) method. Influence of loading rate and film thickness on the tensile properties and work of fracture parameters was evaluated. In addition, energy partition analyses were carried out applying two different approaches ("yielding" and "initiation"), which differ in the treatment of the stored elastic energy. Results showed less effect of the film thickness and deformation rate (<100 mm/min) on the EWF terms. On the other hand, the specific essential work of fracture \( w_e \) at high load rate (1.2 m/s) approached the yielding-related term \( w_{e,y} \) obtained at static loading rates (<100 mm/min).

Introduction
The Essential Work of Fracture (EWF) method, originally proposed by Cotterell and Reddel [1] after Broberg’s work [2], has proved to be a useful tool to characterise the fracture of thin sheets of ductile materials including metals [3] and polymers ([4-9] and references therein). This method proposes the division of the total work of fracture \( W_f \) of a deeply double edge notched tensile (DDENT) specimen (fig.1) into two terms, named essential work of fracture \( W_e \) and non essential work of fracture or plastic work \( W_p \). The first one is a surface-related term and is associated with the energy required to create two new surfaces. \( W_e \) is therefore proportional to the ligament section \( l \cdot t \) where \( l \) is the ligament length and \( t \) is the thickness (fig.1). The plastic work is related with the energy involved in the outer zone of the fracture and is proportional to the volume of the plastically deformed zone \( \beta \cdot l^2 \cdot t \). \( \beta \) is a factor which depends on the shape of the plastic zone.

\[
W_f = W_e + W_p = w_e \cdot l \cdot t + \beta w_p \cdot l^2 \cdot t
\]

Rewriting equation (1) using the specific terms, thus dividing by \( l \cdot t \), we obtain that the specific work of fracture \( w_f \) is a linear function of the ligament length:

\[
w_f = w_e + \beta \cdot w_p \cdot l
\]

By numerical integration of the load-displacement (L-d) curves (see Fig.2-I), the work of fracture \( W_f \) of the specimens at different ligament lengths can be determined.
Then, the specific terms, viz. specific essential work of fracture ($w_e$) and the plastic term ($\beta w_p$) can be determined experimentally by a linear regression drawn for the $w_f$ versus $l$ curves. Many works show that the essential work of fracture, $w_e$ is a material property independent on the test geometry for a given thickness and temperature [4-6]. The non essential work, $W_p$ depends, however, on the shape of the plastic zone surrounding the process zone.

There are some requirements that must be satisfied in order to apply properly the EWF method. Firstly, there must be steady crack propagation through the yielded ligament of the specimen (ductile fracture). Secondly, the fracture of all specimens tested should occur in analogous mode. This can be checked looking at the self-similarity of the L-d curves obtained during the fracture tests (fig. 2-I). Finally, all the specimens must be in the same state of stress during fracture. According to the ESIS protocol, this can be verified if the maximum stress ($\sigma_{max}$) value obtained for each ligament length fall in the range of $0.9\sigma_m - 1.1\sigma_m$ being $\sigma_m$ the mean ($\sigma_{max}$) value (fig 2-II). Hill’s criterion [10] can be used to assure whether plane stress or mixed plane stress/plane strain conditions prevail.