

Keysight Technologies

# Determination of Critical Tearing Energy of Polymer Films

Application Note

## Introduction

Thin polymer films are finding increasing interest in biological sciences and semiconductor packaging, along with their popular application as packaging materials. Researchers also show interest in studying mechanical stresses and fracture behavior in soft biological materials<sup>[1, 2]</sup>. In many of these applications, the films need to experience severe mechanical stresses during handling as well as actual usage. While most of these polymer films are durable under tensile stresses, they are very prone to failure upon tearing. Hence, it is quite important to know the critical energy release rate during fracture of these films for accurate material design.

A common technique to measure the critical fracture energy during fracture of rubber-like materials is trouser-tear test<sup>[3]</sup>. This method got its name because the specimen for these tests consists of a rectangular sheet cut along its long axis to form a trouser shaped sample (Figure 1). The 'legs' of the trouser specimen are then pulled in opposite directions to create tearing action. Determination of critical fracture energy from other test methods requires accurate determination of crack length, whereas the critical energy release and rate of crack propagation during a trouser-tear test are independent of crack length and sample geometry.

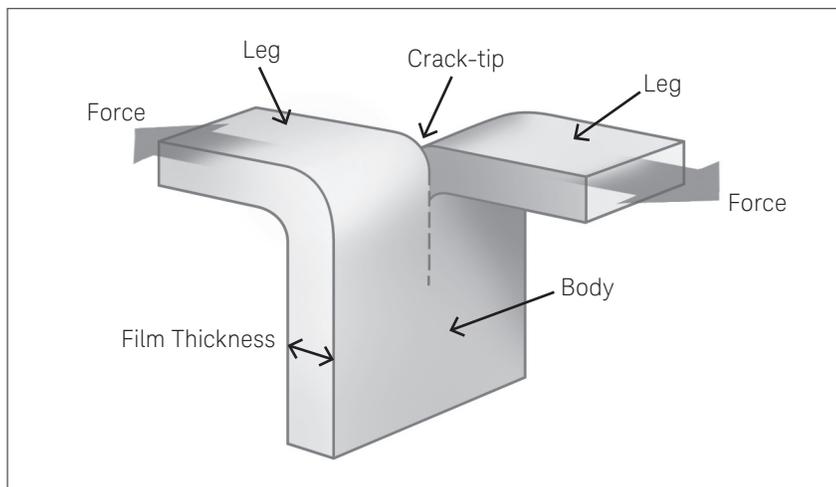


Figure 1. Schematic of trouser-tear test specimen.

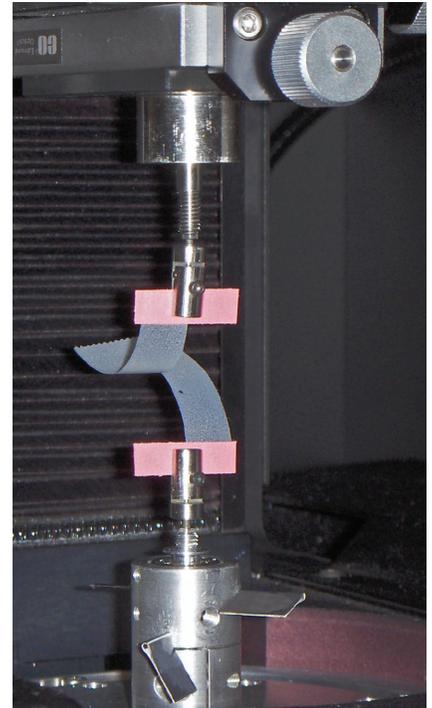


Figure 2. Mounting of tear test specimen in the Keysight UTM T150 using template grips.

The present study determines the critical fracture energies during tearing fracture of two different types of packaging tapes using the Keysight Technologies, Inc. UTM T150.

## Theory

The critical fracture energy from a tear test is also known as ‘tearing energy’, which is the energy spent per unit thickness per unit increase in crack length. This tearing energy includes surface energy, energy dissipated in plastic flow processes and energy dissipated irreversibly in viscoelastic processes. The advantage of using the trouser-tear test lies in the assumption that all these changes in energy are proportional to crack length and are primarily affected by the deformation in the vicinity of the crack-tip. Hence, the total energy is independent of the shape of the test specimen and the way the forces are applied. In other words, although the stress distribution at the tip of a tear crack is complex, it is independent of the crack length<sup>[4]</sup>.

In mathematical terms, the work done during a tear test can be given by

$$\Delta W = 2F\Delta c \quad (1)$$

where, F is the tearing force and  $\Delta c$  is the tear distance [3]. It is important to note here that the changes in extension of the material between the tip of the tear and the legs are negligible and were ignored in this equation.

The tearing energy, or critical fracture energy, can be written as:

$$T_c = \frac{\Delta W}{B\Delta c} \quad (2)$$

where, B is the thickness of the specimen. Hence, by combining Equations 1 and 2:

$$T_c = \frac{2F}{B} \quad (3)$$

It can be confirmed from Equation 3 that the critical tearing energy is independent of the initial sample geometry and crack length. The critical tearing energy could have also been calculated using Equation 2, however more complicated crack length measurement before and after the tear test is needed to achieve good results.

## Experimental Details

Two different polymer tapes were used for the present study; Scotch Magic Tape 810 from 3M (hereby called Sample A), and Permanent Double Stick Tape from Henkel Corporation (hereby called Sample B). From the material safety data sheet (MSDS) of Sample A, the film material is known to be cellulose acetate<sup>[5]</sup>. Such information is not available for Sample B, however most double-sided tapes are usually made of polypropylene. The thickness of Sample A is 59  $\mu\text{m}$ , and that of Sample B is 72  $\mu\text{m}$ . One sharp crack along the long dimension of each specimen was introduced using a sharp razor blade. Then the two ‘legs’ were glued to two small cardboard pieces, and mounted in the UTM T150 using the standard template grips, as shown in Figure 2. The tearing tests were performed under quasi-static loading at an extension rate of 100  $\mu\text{m/s}$ . The load on specimen and specimen extension values has been recorded during loading, tearing and unloading of the specimen. Three different specimen of each type of polymer tape were studied to get an idea about the statistical variation.

## Results and Discussion

The load-extension curves for samples A and B are shown in Figures 3(a) and 3(b), respectively. It is clearly evident from these results that it takes much lower force to tear Sample A compared to Sample B. The nonlinear segments of the curves, prior to tearing and during unloading correspond to stored strain energy in the legs of the specimen. The average force during the tearing process for Sample A is 49 mN and that for Sample B is 100 mN. It is important to note here that the small fluctuations in the force values during tearing are not noise from the instrument but rather due to the stick-slip behavior observed during fracture in many polymers. The maxima occur when the crack extends and the minima represent crack arrest [6]. The interval of these fluctuations most probably relates to the morphology of the material, such as the distribution of crystalline and amorphous phases. However, systematic microstructural characterization is needed to fully understand the stick-slip behavior. The calculated tearing energies (Equation 3) for both samples are listed in Table 1, along with the tearing force and film thickness. Sample B exhibits higher tearing energy compared to Sample A. In other words, one would use Sample B in applications where higher resistance to tear is needed. Hence, this is a parameter of particular interest for designing materials and microstructures of thin polymer films for different applications. Note that the exact nature of the material morphology and its effect on the tearing energy was out of scope for this study. Future work in this direction can potentially shed more light on the fracture process of different polymer films.

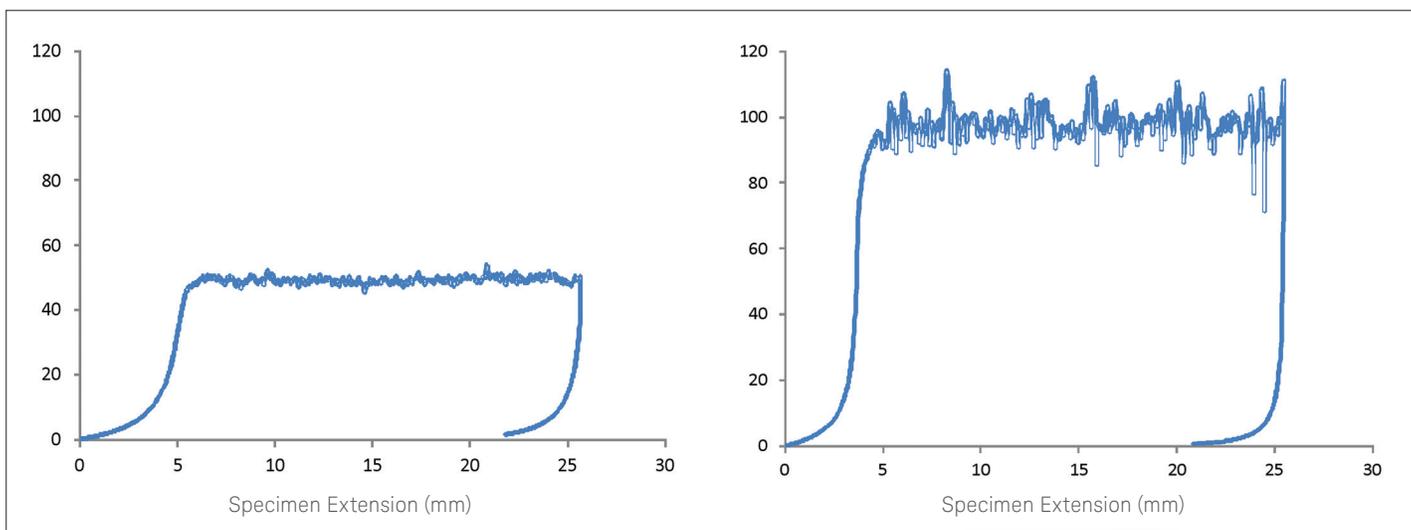


Figure 3. Load-extension response during the trouser tear test for (a) Sample A, and (b) Sample B.

|          | Film thickness<br>( $\mu\text{m}$ ) | Tearing force<br>(mN) | Critical tearing energy<br>(N/m) |
|----------|-------------------------------------|-----------------------|----------------------------------|
| Sample A | 59                                  | 52 $\pm$ 2            | 1750 $\pm$ 80                    |
| Sample B | 72                                  | 97 $\pm$ 1            | 2700 $\pm$ 22                    |

Table 1. Results of trouser-tear tests on polymer films.

## Conclusions

The critical tearing energy for two commercially available polymer tapes are measured from trouser-tear tests using the UTM T150. The capability of measuring small loads, along with the high force resolution, enabled us to capture the variations in force during tearing of thin polymer films, which should inspire new studies to determine the effect of morphology and crystallinity on the exact nature of crack propagation in thin polymer films. Similar tear tests can also be performed on other biological samples, such as microalgae, where it is difficult to control the sample dimensions.

## References

1. Mach, K.J., D.V. Nelson, and M.W. Denny, *Techniques for predicting the lifetimes of wave-swept macroalgae: a primer on fracture mechanics and crack growth*. Journal of Experimental Biology, 2007. 210: p. 2213–2230.
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