Society of Plastics Engineers
PLASTICS RESEARCH ONLINE

10.2417/spepro.005931

Toughness of center-cracked polypropylene films

Arzu Hayirlioglu Topuzlu and Hoang Pham

A simple tensile test method that uses the strain energy of materials predicts the failure strength of multilayer films.

When introduced into polymers, impurities such as gels, dirt, and other contaminants can lead to defect formation. This can result in breakage of the polymeric film and subsequent downtime during cast-film manufacturing. Elimination of these imperfections is therefore desirable. To discover a correlation between product defects and their associated failure, the creation of a reproducible and reliable test method is key. Fracture mechanics have been used to this end in a variety of different materials, particularly metals, and can be adopted to improve our knowledge of polymeric materials.[1]

Numerous groups have studied the effect of polypropylene (PP) homopolymer geometry, testing rate, and temperature on the resultant polymer properties. One of the most common methods, linear elastic fracture mechanics (LEFM), is able to quantify the fracture toughness of brittle materials.[2] Another approach, elastic-plastic fracture mechanics (EPFM), was developed to address the non-negligible elastic-plastic material behavior at the plastic area around the crack tip. Later, elastic work of fracture (EWF) enabled the fracture mechanism in materials with large plastic deformation to be defined.[3–6] However, the fracture toughness defined by EWF does not explain the work that initiates or propagates the crack.

We have developed an alternative method for studying the effect of defect size and temperature on the failure of a polymer film.[7] By introducing a slit crack in the middle of the thin-film samples, film toughness can be assessed as a function of defect size. Due to ductile deformation around the crack tip of the test specimen, the resultant strain energy can be used to interpret the results, providing a simple way to correlate the data.

We obtained multilayer-cast PP film by using four single-screw extruders. Extruder and cast temperatures were 215 and 60°C, respectively. Center cracks of 1, 2, 3, 4, and 4.35mm were introduced in the cast-film sheets (see Figure 1) using surgical scalpels and a steel ruler. Under test temperatures of 23 and 40°C, we observed no stress whitening at the edge of cracks.

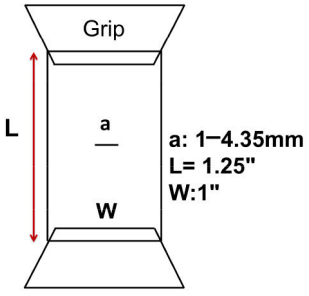

Figure 1. *Geometry of the center-cracked polypropylene (PP) samples. L: Length. W: Width. a: Crack length.*

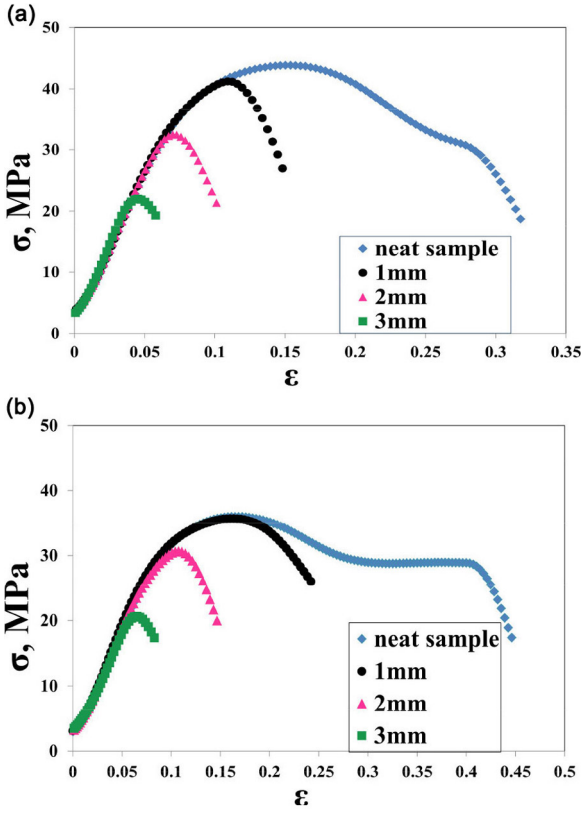

Figure 2. *Stress (σ) vs. strain (ε) graph of neat and 1, 2, and 3mm center-notched PP samples at (a) 23 and (b) 40°C.*

Continued on next page

We used an MTS Sintech 1/G to measure the tensile properties of the films, which were stretched at a speed of 203cm/min. The stress-strain data was collected for both temperature conditions: see Figure 2(a) and (b). At the higher temperature, uncracked PP films show higher ductility compared to the lower-temperature samples due to greater yield at the crack tip. Similarly, increasing the center-crack length results in a reduction of elongation at break for the PP samples to 5% of the initial length at 23°C and 8% at 40°C. On the other hand, the yield stress decreases with increasing crack length, indicating that the crack length has an influence on the sample toughness (see Figure 2). We used the strain energy of the sample to estimate its toughness.

The strain energy at break (G_b) of center-cracked PP samples is plotted against the center-crack sizes in Figure 3(a). Increasing the crack length decreases G_b. Additionally, we determined the strain energy that contributes to the yielding of the film and plotted this property against the crack length—see Figure 3(b)—showing that with a crack length of more than 3mm, both the break and yield energy reach an asymptotic value. We were able to observe the failure mechanism under a microscope to show localized yielding at the crack tip and a subsequent brittle-like failure. Since the crack is already unstable above 3mm, it does not show further deformation around the crack tip.

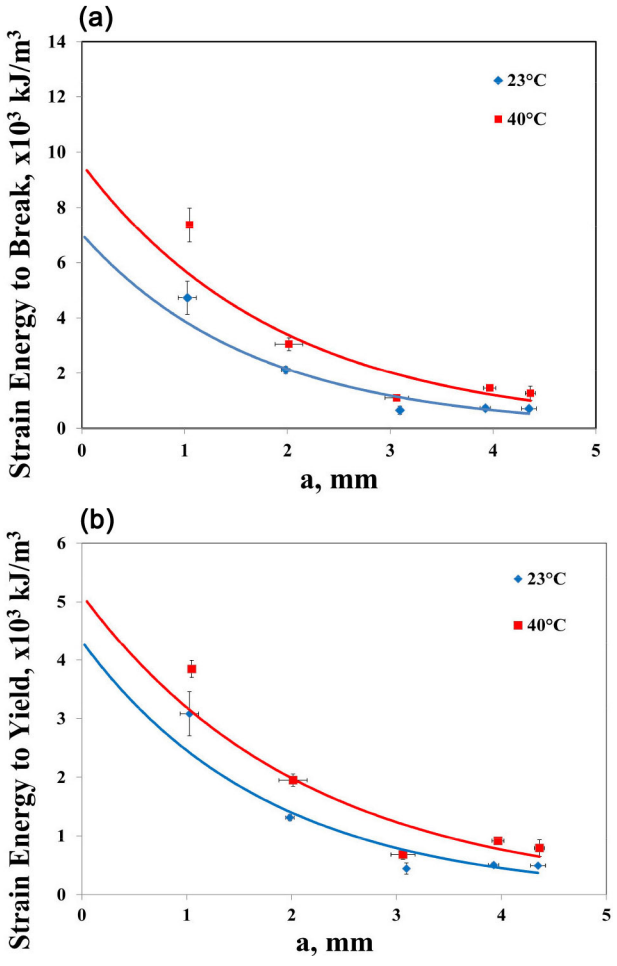

Figure 3. *(a) Strain energy at break vs. initial crack length at 23 and 40°C. (b) Strain energy at yield for the ligaments on both sides of the crack vs. initial crack length at 23 and 40°C.*

In summary, we have developed a practical lab-scale test method for simulating the failure observed in high-speed manufacturing processes. For this purpose, we tested cast-PP homopolymer films by creating center-cracked test specimens. The results indicate that at critical crack lengths (3–4mm), samples showed a ductile-to-brittle-like transition under both 23 and 40°C conditions, whereas neat PP-homopolymer films tend to show ductile behavior at both temperatures. This transition was observed at a crack length of 3mm, above which brittle failure occurs due to the instability of the crack. In future work, we intend to define the test conditions that enable stable crack growth, allowing further study into the effects of high-speed manufacturing processes on polymeric materials.

Author Information

Arzu Hayirlioglu Topuzlu and Hoang Pham
Avery Dennison Corporation
Mentor, OH

Arzu Hayirlioglu Topuzlu has BSc degrees in chemical and environmental engineering and an MSc in polymer science and technology from Istanbul Technical University, Turkey. She received her PhD degree in polymer engineering at the University of Akron, OH, in 2014 and later joined the Avery Dennison Corporation as technology leadership associate.

Hoang Pham is a principal engineer at the Avery Dennison Corporation. He has a PhD from the University of Akron, OH, and is a board member in the Engineering Properties and Structure Division at SPE.

Continued on next page

References

1. W. Grellman and S. Seidler, **Deformation and Fracture Behavior of Polymers**, Springer, Berlin, 2001.
2. P. L. Fernando and J. G. Williams, *Plane stress and plane strain fractures in polypropylene*, **Polym. Eng. Sci. 20** (3), pp. 215–220, 1980.
3. B. Cotterell and J. K. Reddel, *The essential work of plane stress ductile fracture*, **Int'l J. Fract. 13** (3), pp. 267–277, 1977.
4. K. B. Broberg, *Critical review of some theories in fracture mechanics*, **Int'l J. Fract. 4** (1), pp. 11–19, 1968.
5. M. L. Maspoch, D. Ferrer, O. O. Santana, and J. I. Velasco, *The essential work of fracture of polyolefinic films*, **ESIS**, pp. 1423–1428, 1998.
6. C. Grein, C. J. G. Plummer, Y. Germain, H.-H. Kausch, and P. Béguelin, *Essential work of fracture of polypropylene and polypropylene blends over a wide range of test speeds*, **Polym. Eng. Sci. 43** (1), pp. 223–233, 2003.
7. A. H. Topuzlu, H. Pham, L. Grant, A. Xue, Y. Patil, and A. Poslinski, *Toughness study of center cracked polypropylene films with temperature effect*, **Proc. SPE ANTEC**, 2015.