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An investigation of cutting resistance in stretched polymer films

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Abstract

An investigation is made into the fracture properties of polymer films and laminates under cutting by a sharp tool and lateral tension under pure shear conditions. The method involves use of a sharp razor blade applied to the crack tip of polymer films which are also stretched orthogonal to the direction of the blade. The reaction force is measured as the cutting tool cuts the material and the force from applying a lateral strain is measured. The analysis and tests assume quasi-static conditions. The method is applied to a polyester film and three polyester laminates.

Steady-state cutting forces are observed from cutting tests and loads at crack initiation are observed from lateral stretching tests. With fracture mechanics analysis the energy contributions from cutting and tearing are used to determine apparent fracture properties from the experimental results. It is observed that the cutting and tearing tests yield similar fracture toughness properties for the three tested polyester laminates, despite the different crack tip geometry at the point of crack growth. However, significantly larger fracture toughness values are measured from tearing tests versus cutting tests for the tested polyester film.

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1. Introduction

The use of cutting tests can be an effective alternative for when standard fracture toughness tests cannot be used. A common way to measure fracture toughness of polymers is by critical G or K testing, which have established

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standards. However, it can be difficult to determine toughness using the traditional methods such as when polymers have high toughness, low modulus, low yield stress or when the material is difficult to shape. Other common problems are stable crack growth prior to instability or crack tip blunting, which are a nature of the fracture process. A popular approach has been the use of J-integral testing which was initially developed for metals (ASTM E1820-08). This method has also been applied to polymers (ASTM D6068-96) and has been favoured for testing low density polyethylenes by Hashemi and Williams (1986). One alternative fracture toughness testing method is to use cutting or machining tests. Patel et al. (2009) have explored machining tests to determine fracture toughness in tough polymers. For rubber, experimental work on stretched natural rubber vulcanizate sheet has been used to determine fracture toughness properties by Lake and Yeoh (1978). These involved use of a razor blade applied to a pre-cracked rubber sheet loaded laterally.

This method of cutting with a sharp tool with lateral stretching is investigated for selected polymer films with thickness between 15 μm and 70μm. The investigation hopes to explore the value of such a method to determine fracture toughness properties for polymer films and to understand the criteria for fracture initiation.

Nomenclature

f	Cutter force
h	Width
l	Length
t	Thickness
E	Young's modulus
F_c	Energy associated with cutting
G	Strain energy release rate
G_b	Apparent fracture toughness
K	Stress intensity factor
T	Energy associated with tearing
W	Strain energy density
σ	Stress

2. Experimental method

Cutting by a sharp razor blade is applied directly to the crack tip of a specimen of thickness t, unstrained width h and length l under pure shear conditions. The specimen is held at a fixed width by two clamps while the razor blade is moved at a constant rate vertically towards a pre-made crack tip in the specimen. The reaction force on the blade is measured using a piezo-electric load cell. The experimental setup is shown schematically in Fig 1. The razor blade material is stainless steel with a tip radius of 2 μm. The cutting rates used are such that quasi-static conditions can be assumed.

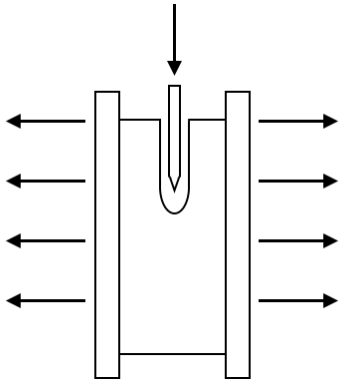

Fig. 1. Schematic diagram of cutting stretched polymer film by a razor blade.