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The Partitioning of Plastic Energy in Cutting Tests

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Abstract

Cutting analyses incorporating chip bending in addition to shear yielding and fracture toughness have been presented. A plastic bending term $(e_b/\gamma)(h_c/h)$ is included which corrects the yield stress, σ_Y, determined from the cutting data. The experimental data for seven polymers derived from measuring both the chip thickness and the residual radius of curvature show that the contribution of bending is up to about 12%. This gives a correction to σ_Y of about the same order but G_c is unaffected as $(e_b/\gamma)(h_c/h)$ is a factor independent of the cutting depth. The corrected σ_Y values are compared with the σ_Y values in simple compression and it suggests a work hardening effect for the polyolefines. Also, the low bending strain in the chips of HMWPE and PP may be attributed their large degree of non-linearity observed in the compression test.

Keywords: cutting, chip bending, fracture toughness, polymers, work hardening

1. Introduction

Orthogonal cutting tests have been employed in the determination of the fracture toughness of polymers [1]. Sharp tools with an angle θ are used to cut surface layers of varying thickness, h, and the cutting force F_c and transverse force F_t are measured as shown in Fig. 1 (a). As drawn in Fig. 1, the deformation mode in the chip is bending and for large radii of curvature the deformation is elastic giving no plastic deformation and hence no energy dissipation. On unloading the chip would be straight. For larger angles and smaller thicknesses, the radius of

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curvature decreases leading to elastic-plastic bending and permanent curvature, i.e., chip curling, as shown in Fig. 1 (b).

For larger angles and smaller thicknesses, there is a further transition to plastic shearing along a plane at an angle φ, as shown in Fig. 1 (c). This results in straight chips but with large plastic shear strains. This is the case used for determining the fracture toughness G_c and the forces are proportional to h so that extrapolation to F_c/b at zero thickness gives an intercept of G_c. There is also energy dissipation via friction at the tool-chip interface and this can be determined via the transverse force F_t/b [1]. The testing method [2] assumes that the deformation is all via shear and the h values are chosen to ensure that this is the case. However, it has been observed that, for some materials, chips with a finite residual curvature occur so that some of the energy dissipation is via bending. The effect of this on the analysis of results is explored here by measuring the residual curvatures of the chips and making corrections.

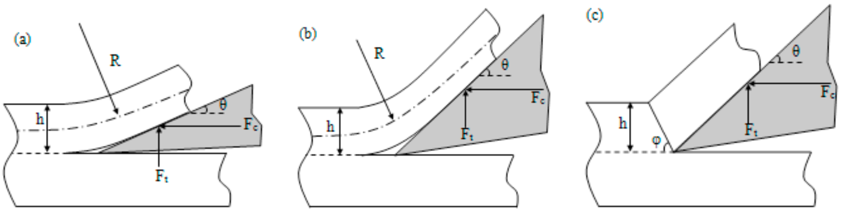

Fig. 1. (a) Elastic bending, (b) elastic-plastic bending and (c) plastic shearing.

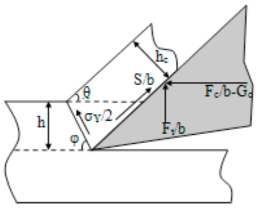

Fig. 2.Geometry of shear solution.

Nomenclature			
		e_Y	yield strain in compression as defined in Fig. 3
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Greek Alphabet		E	Young's modulus
γ	shear strain in cutting	e_b	bending strain in the chip
θ	tool angle	F_c	cutting force
σ	stress	F_t	transverse force
σ_Y	yield stress	G_c	fracture toughness determined via cutting test
φ	shear plane angle in cutting	h	cutting depth
		h_c	chip thickness
English Alphabet		M_p	moment at full yielding ($\sigma_Y bh^2/4$) in the chip
b	width of cut	N	normal force on the tool face
dx	tool movement	R	radius of curvature
dx_c	distance moved by force S	R_i	radius of curvature of the inner part of the chip
du_s	shear displacement	R_o	radius of curvature of the outer part of the chip
e	strain	S	shear force on tool face

2. Analysis

We first consider the energy analysis [3] of the shear case which is shown in Fig. 2. Assuming plane strain condition, i.e. b>>h, there is a constant area for the deformation and,