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Physical cutting model of Polyetheretherketone composites

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Abstract

This paper presents a study on the experimental physical model of the orthogonal cutting on the composite polyetheretherketone (PEEK) and PEEK CF30 (reinforced with 30% of carbon fiber). The objective of this study is evaluating the influence of the reinforcement on the chip thickness ratio (R), chip deformation (ε), friction angle (ρ), shear angle (ϕ), normal stress (σ) and shear stress (τ) under prefixed cutting parameters (cutting velocity and feed rate). The experimental physical model was compared with the Merchant equation.

Keywords: Orthogonal cutting; Merchant equation; Polyetheretherketone (PEEK); Polycrystalline diamond (PCD)

1. Introduction – background of the orthogonal cutting model

Machining is a manufacturing process where a cutting tool is used to remove the excess material. Merchant presented in 1945 the fundamentals of the mathematical model of the metal cutting process [1,2]. Recently, the interest of machining polymeric composite materials by conventional techniques has grown. The orthogonal cutting is discussed in terms of the fibre orientation, tool wear and cutting forces [3,4].

The orthogonal cutting model can be used to approximate turning and certain other single-point machining operations as long as the feed is small relative to the depth of cut [2]. Orthogonal cutting model is based on the following assumptions [1,5] (Fig. 1):

- the cutting edge is perpendicular to the direction of motion;
- the tool has only two elements of geometry, rake angle and clearance angle;
- the shear surface is a plane extending upward from the cutting edge;
- the chip does not flow to the either side (plane strain);
- the depth of cut is constant;
- the shear and normal stresses along shear plane and tool are uniform.

The orthogonal cutting is defined by having a cutting edge position (χ) of 90° and a cutting edge inclination (λ) of 0°. Under these conditions, a plane chip is formed . The chip thickness ratio or cutting ratio (R) is the quotient of the undeformed-chip thickness (e) to the chip thickness after cutting (e') [2,5],

$$R = \frac{e}{e'}. \qquad (1)$$

The chip thickness ratio will be less than 1.0 because the chip thickness after cutting is greater than the corresponding undeformed-chip thickness, due to the frictional conditions existing at the chip-tool interface and the plastic deformation of chip [6]. In consequence, the chip thickness depends on the work and tool materials and the cutting parameters.

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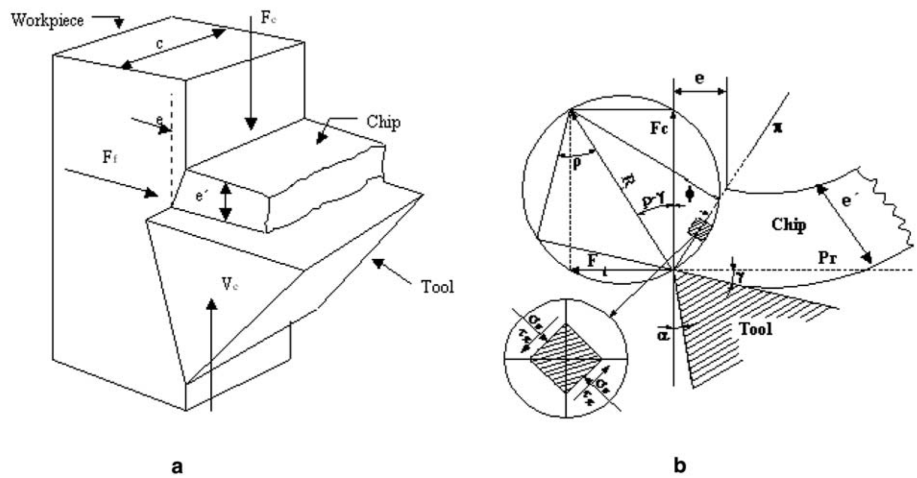

Fig. 1. Orthogonal cutting model: (a) Interaction tool-workpiece and chip formation; (b) *Merchant* model.

The inverse chip thickness ratio is [1,2,5]

$$R_c = \frac{1}{R} = \frac{e'}{e} \tag{2}$$

The shear angle (ϕ) can be calculated from the inverse chip thickness ratio by the following equation [1,2,5,6]:

$$\phi = \text{arctg}\frac{\cos\gamma}{R_c - \sin\gamma}, \tag{3}$$

where R_c is the inverse chip thickness ratio and γ the rake angle.

From cutting forces and shear angle, the shear and normal stresses (N/mm^2) along shear plane can be calculated as [1,2,5,6] as

$$\tau = \frac{F_c\cos\phi - F_t\sin\phi}{c\cdot e}\sin\phi, \tag{4}$$

$$\sigma_= \frac{F_c\sin\phi + F_t\cos\phi}{c\cdot e}\sin\phi, \tag{5}$$

where F_c is the cutting force (N), F_t the thrust force (N), ϕ shear angle (°), c the width of the cut (mm) and e the undeformed- chip thickness (mm).

The chip deformation can be obtained from the values of R_c and γ [1,2,5,6]:

$$\varepsilon = \frac{1 + R_c^2 - 2R_c\sin\gamma}{R_c\cos\gamma} \tag{6}$$

The shear angle (ϕ) is angle at which shear stress is just equal to the shear strength of the work material, and so shear deformation occurs at this angle. The shear angle can be determined by taking the derivative of the shear stress (Eq. (4)) with respect to ϕ and setting the derivative to zero, according to Merchant [1]

$$\phi_M = \frac{\pi}{4} - \frac{1}{2}(\rho - \gamma). \tag{7}$$

The mean friction angle (ρ) and friction coefficient (μ) can be estimated from the cutting forces (F_c and F_t) and the rake angle (γ) by the following equation [1,4,5]:

$$\mu = \text{tg}\rho = \frac{F_c\sin\gamma + F_t\cos\gamma}{F_c\cos\gamma - F_t\sin\gamma}. \tag{8}$$

Eq. (7) defines the relationship between rake angle, tool-chip friction and shear angle. A higher shear angle results in a smaller shear plane area and consequently in a smaller force required to form the chip [1].

Generally, it is perceptive to consider a value of δ, that is named "machinability index" or *Merchant* constant, according to Eq. (9) (corrected *Merchant* equation), to calculate the shear angle [1,5].

$$\phi_{Mc} = \frac{\delta}{2} - \frac{1}{2}(\rho - \gamma). \tag{9}$$

2. Experimental procedure

The objective of this experimental work is to evaluate the influence of the reinforcement carbon on the cutting model during the turning process of small workpieces under the prefixed cutting parameters . Unreinforced polyetheretherketone (PEEK) and PEEK reinforced with 30% of carbon fibers (PEEK CF30) supplied by ERTA® were used. The mechanical and physical properties of materials are described in Table 1.

The experiments were carried out in extruded workpieces with a diameter of 50 mm and a length of 100 mm, using a polycrystalline (PCD) insert tool (DCMW 11T3 04FPDC10). A type SDJCL 2020 K11 tool holder was used. The tool presents the following geometry: clearance angle 7°, rake angle 0°, cutting edge angle 93° and cutting edge inclination angle 0°.

A CNC lathe "Kingsbury MHP 50" with 18 kW spindle power and a maximum spindle speed of 4500 rpm was used to perform the experiments.