EVALUATION OFF CUTTING FORCES IN THE ORTHOGONAL CUTTING OF POLYMERIC COMPOSITES MATERIALS

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ABSTRACT

Milling and drilling are the two machining operations most frequently involved in manufacturing parts made of fiber reinforced polymeric. Composites-specific quality criteria must know in order to asses the machining results.
This paper presents a model for the prediction in machining operations of composite materials. The concept of chip is used to obtain the relation between force and cutting conditions.

KEYWORDS: cutting forces, composites, chip

1. INTRODUCTION

Polymeric composite materials have rapidly achieved important status in every industry. The main reason for enlargement of their field of application was the improvement of their physical properties such as fatigue strength stiffness, low specific weight, corrosion strength and impact strength.
Due to their anisotropy and inhomogeneity, these materials can suffer considerable damage during cutting process. In general, in order to eliminate damage in machining composite materials, a substantial reduction in cutting forces is required.
In this paper, a theoretical model is presented, aiming to predict cutting forces in orthogonal cutting of unidirectional composites a function of machining parameters ant word material properties. This model is used when the cutting speed coincides with fiber direction.
The forces developing during the contact between tool and work piece are divided in two parts, one of which acting at the tool face, and the other at the tool flank.

2. THEORETICAL MODEL

When a directional composite is cut parallel to the fiber direction it produces a delamination, which is similar in length to the chip thickness (figure 1) [2].

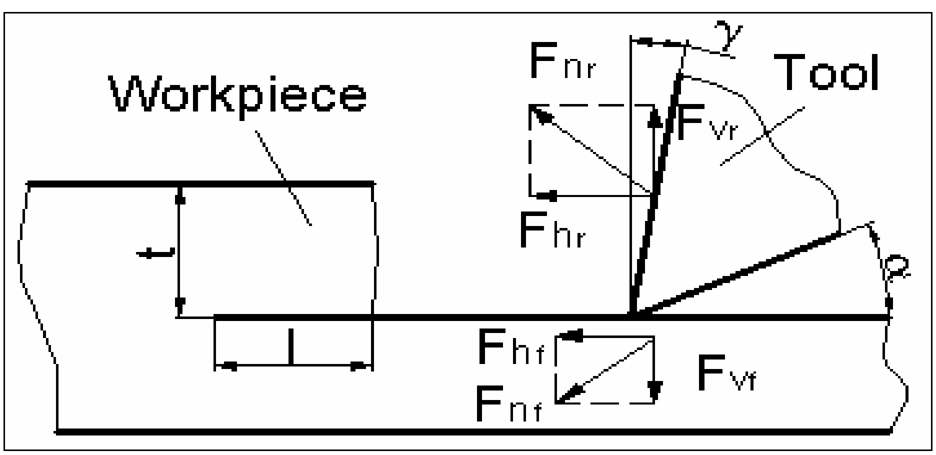

Figure 1

The stages of the chip formation are fallowing:

- under the action of the tool face, a delamination forms at the tool tip;
- the chip, not completely detached from the workpiece, is loaded by the tool face, until it breaks;
- the tool engages new work material, and the process repeats itself.

Another source of force generation is tool flank, where the tool compresses the workpiece and a friction force arises, due to the continuous material sliding. The forces at the tool flank contribute considerably to the total cutting forces, at least when small relief angles are utilized. Referring to the symbols in fig. 1, and assuming a unit width of cut, the relations:

$$F_h = F_{hr} + F_{hf} \quad (1)$$

$$F_v = F_{vr} - F_{vf} \quad (2)$$

where: F_h and F_v are the overall horizontal and vertical cutting forces per unit width.

The total horizontal and vertical cutting forces can be calculated, provided their components at the tool face and flank are known. The force applied at the tool face is assumed that is only supported by the chip, and its critical value is calculated according to the Tsai-Hill strength criterion [1]. Subsequently, the force at the tool flank is calculated.

2. 1 FORCES AT THE TOOL FACE

Because the chip formation in composite machining is based on brittle fractures, it not takes place a sliding along the tool face, so that, to be considerate that the overall force on the tool face is perpendicular to the face itself, resulting the followings:

$$F_{hr} = F_{nr} n \cos\gamma \quad (3)$$

$$F_{vr} = -F_{nr} \sin\gamma \quad (4)$$

where: F_{hr} and F_{vr} are the horizontal force respectively vertical force at the tool face; F_{nr} – overall force at the tool face; γ – rake angle.

From egs. (3) and (4):

$$F_{vr} = -F_{hr} \tan\gamma \quad (5)$$

The vertical force subjects to bending and shear the forming chip, whereas the horizontal force generates compression stresses. Making out the chip as a short beam, clamped at an edge and subjected to compression and shear by action of the forces Fhr and Fvr, respectively, can be calculate the state of stress:

$$\sigma = \frac{F_{hr}}{t} \quad (6)$$

$$\tau = -\frac{F_{hr} \tan\gamma}{t} \quad (7)$$

where: t represents the depth of cut and it is similarly in length whit the delamination length l.

Using the Thsai-Hill criterion (8), it obtains F_{hr} (9), [3].

$$\left(\frac{\sigma}{X}\right)^2 + \left(\frac{\tau}{S}\right)^2 = 1 \quad (8)$$

$$F_{hr} = t \times \frac{X \times S}{\sqrt{X^2 \tan^2\gamma + S^2}} \quad (9)$$

where: X represents the compression strength of unidirectional composite; S – shear strength.

It is seen that, when he rake angle is 0^0, the chip failure is only due to compression, and when the rake angle increases the chip failure is essentially provoked by shear. It is important to notice that, both the horizontal and vertical force at the tool face is linear dependent on the depth of cut, t.

2. 2 FORCES AT THE TOOL FLANK

When the tool is perfectly sharp and the radius of curvature at the tool nose is nil, both the chip and the workpiece are subjected to on intense state of stress. An elastic recovery in the vertical direction will take place immediately after the chip separation from the machined surface. In the case in which the tool is not perfectly sharp, the machined surface is formed along a plane located at an unknown distance z from the plane A-A individuated by lowest point of the tool (fig. 2)

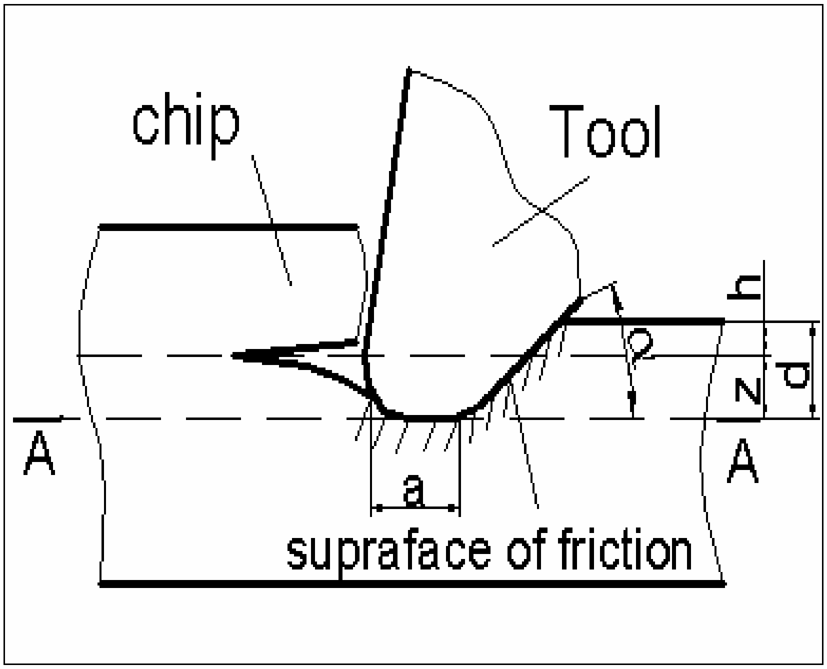

Figure 2

At the same time, friction foces are generated along the contact surface between tool and workpiece.
In this paper, the profile of the contact surface is considered that to be represented by two segments. The tightness z representing the effect of the radius at the tool tip and h representing the effect at the elastic recovery, are unknown.
In order to find the stress distribution along the contact surface, it is assumed that the compression of the tool against the work gives rise to vertical stress proportional to the displacement of the material whit respect to its undeformed state “d”. In this hypothesis, the vertical force per unit width, F_{vf}, is given by [1]:

$$F_{vf} = K_1 \times (z+h)\left[a + \frac{(z+h)}{2\tan\alpha}\right] \qquad (10)$$

where: K1 is a constant, only dependent on the material elastic properties.
Since the maximum F_{vr} value is directly dependent on the share strength of the unidirectional composite, which is quite low, the effect of the vertical force at the tool face on h can be disregarded, and a linear dependence of h an F_{hr} can be supposed [2]:

$$h = K_2 \times F_{hr} \qquad (11)$$

where: K2 is a constant, dependent on the material elastic properties.
Putting h into eg. (10) becomes:

$$F_{vf} = K_1 \times (z + K_2 \times F_{hr})\left[a + \frac{(z + K_2 \times F_{hr})}{2\tan\alpha}\right]$$

The horizontal force F_{hf}, is simply calculated multiplying F_{vf} by the dynamic coefficient of friction, “f”.

$$F_{hf} = f \times F_{vf} \qquad (12)$$

2. 3 TOTAL CUTTING FORCES

The total cutting forces are calculated from egs. (1) and (2), where Fhr, Fvr, Fhf and Fvf are given by egs. (9), (5), (12) and (10).

3. APPLICATIONS OF THE THEORETICAL MODEL

It is considerate a unidirectional composite bar realized using 42% E glass fibers (the matrix is Modar 826 HT acrylic resin) which is machined with a low cutting speed (v = 0,46 m/min), to avoid thermal effects on both the tool and the workpiece. The cutting speed was parallel to the fibre direction and the tool material was high speed steel.

The rake angles adopted for tool was by 9^0 and the depth of cut was by 0,12 mm.

For calculation of cutting forces it is adopted: the value of dynamic coefficient of friction is f = 0,29; compression strength X = 315 N/mm^2; shear strength of composite S = 30,3 N/mm^2.

For adopted values it is obtained for cutting forces, the following values: F_{hr} = 19,62 N şi F_{vr} = 3,1 N, F_{vf} = 23,29 N, Fhf = 6,75 N.

CONCLUSIONS

The starting point of the theoretical model for predictions cutting forces is the assumption that, a delaminating of length comparable with the depth of cut runs parallel to the fibre direction ahead of the tool nose.

The cutting forces are dependent on the tool geometry, through the race angle and the relief angle. The material strengths also affected cutting forces, through te compression strength X and the interlaminar shear strength S. Finally, a role in determining the horizontal cutting force at the tool flank is also played by the dynamic coefficient of friction, f.

The values of cutting forces for unidirectional composite material reinforced with glass fibres are to near to the calculate values whit theoretical model and to the experimental values, which are presented by special literature.

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