BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 63 (67), Numărul 2, 2017
Secţia
CONSTRUCŢII DE MAŞINI

EXPERIMENTAL EVALUATION OF INFLUENCE OF RAKE ANGLE ON SPECIFIC CUTTING FORCE

BY

CRISTIAN CROITORU[1,*], ANA MARIA BOCĂNEŢ[1], ROMEU CHELARIU[2] and **DANIELA CHICET[2]**

“Gheorghe Asachi” Technical University of Iaşi,
[1]Faculty of Machine Manufacturing and Industrial Management
[2]Faculty of Materials Science and Engineering

Received: October 16, 2017
Accepted for publication: November 20, 2017

Abstract. In this paper is presented a graphical-analytical method to estimate the influence of a geometric parameter of a cutting tool on the specific cutting force.

Starting from the Kienzle approach of the cutting force, an experimental plan was developed, which emphasized the influence of the rake angle γ (cutting angle δ) on the constants in the specific cutting force relationship

As a result of the present study, two simple analytical expressions of the unit specific cutting force $k_{c1.1}$ (nominal specific cutting force) and of the exponent m_c having high potential for practical use are presented.

Keywords: specific cutting force; cutting angle; dry machining; Al-Cu alloy.

1. Introduction

Reliable prediction of cutting forces plays an important role in determining the processing costs depending on the material of the workpiece, the cutting tool material, the working conditions and the cutting tool geometry.

*Corresponding author; *e-mail*: ccroitoru@tuiasi.ro

The difficulty of predicting the cutting forces is amplified by the variety of processed materials and the large number of cutting tools utilized currently.

This is the reason why a series of methods of approximation of the cutting forces have been developed, based both on analytical models and empirical models. Compared to analytical models, empirical models are more precise but have a lower degree of generality.

For this purpose there are known a series of studies on the effect of the parameters of the cutting regime and the rake angle on cutting forces for different materials (Günaya *et al*., 2005; Haci *et al*., 2006; Gonzalo *et al*., 2010).

2. Empirical Approach

Starting from the linear proportion of the tangential cutting force F_c and the area of the undeformed chip, Kienzle established relation (1):

$$F_c = k_c \cdot A = k_c \cdot h \cdot b \tag{1}$$

where, in case of turning:
- k_c is the specific cutting force;
- b is the theoretical chip width (Fig. 1);
- h is the theoretical chip thickness;
- a_p is the depth of cut;
- f is the feed.

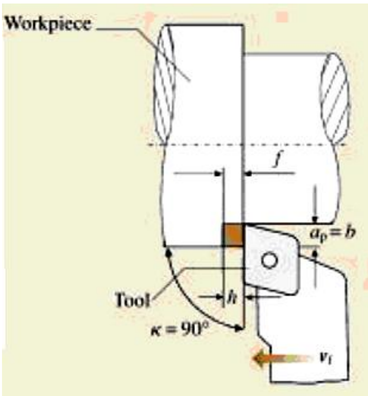

Fig. 1 − Cut and chip variables in turning.

Another form of relation (1) is described in terms of an exponential curve according to Eq. (2):

$$F_c = k_{c1.1} \cdot b \cdot h^{1-m_c}, \tag{2}$$

where $k_{c1.1}$ is the unit specific cutting force or nominal specific cutting force (*i.e.* $k_{c1.1}$ is k_c at h=b=1) and m_c is an exponent which measure the rise of specific cutting force with decrease of theoretical chip thickness. The two constants $k_{c1.1}$ and m_c are listed for various materials (Toenshoff and Denkena, 2013).

In order to determine values of the two constants $k_{c1.1}$ and m_c, a graphic-analytical method is usually used (Klocke, 2011).

According to this method, the linear equation corresponding to Eq. (2) is considered:

$$\lg \frac{F_c}{b} = \lg k_{c1.1} + (1 - m_c) \cdot \lg h, \tag{3}$$

the values of constants $k_{c1.1}$ and m_c are to be obtained by using different points of an experimental plane (Sekulic *et al.*, 2010; Croitoru *et al.*, 2015).

3. Results

In order to achieve the proposed objective, a working methodology has been adopted according to the above described.

3.1. Machining Conditions

Experiments were performed on a conventional lathe SNA 560x1500.

The workpiece material utilized in this experiment was AlCu11, an Al-Cu alloy having 88.6% Al and 11% Cu.

The test specimens were in form of cylindrical bars having 50 mm diameter and 70 mm length.

The tests were carried out with an uncoat carbide P20, tool insert having a cutting-tool geometry given below (Figs. 2 and 3).

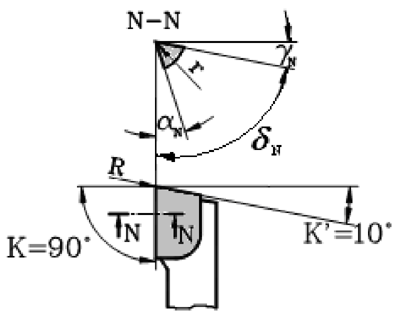

Fig. 2 − Geometric features of the utilized cutting tool.

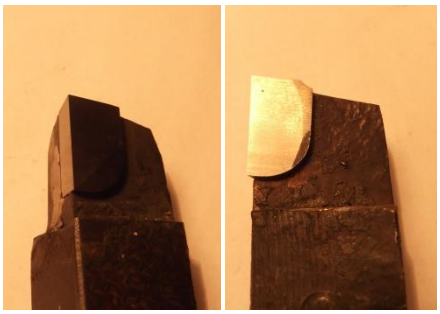

Fig. 3 − Cutting tool for γ_N = 0° (δ_N = 90°) and for γ_N = + 10° (δ_N = 80°).

- major cutting angle K = 90°;
- minor cutting angle K' = 10°;
- nose radius R < 0.05 mm;
- inclination angle λ = 0°;
- clearance angle α_N = 10°;
- cutting edge roundness r < 0,02 mm;
- rake angle γ_N = 0°, 10° and 20° (cutting angle δ_N = 90°, 80° and 70°).

In order to achieve an as low as possible level of plastic deformation of the material in the cutting zone, a very small nose R radius was adopted.

The selected turning dry conditions are presented below:

- cutting speed V_c = 89...95 m/min;
- feed rate f = 0.10; 0.14; 0.18 and 0.22 mm/rev.

3.2. Determining the Specific Cutting Force

The cutting force components were collected in three orthogonal directions at a sampling rate of 1 kHz with a piezoelectric dynamometer Kistler 9272 (Fig. 4).

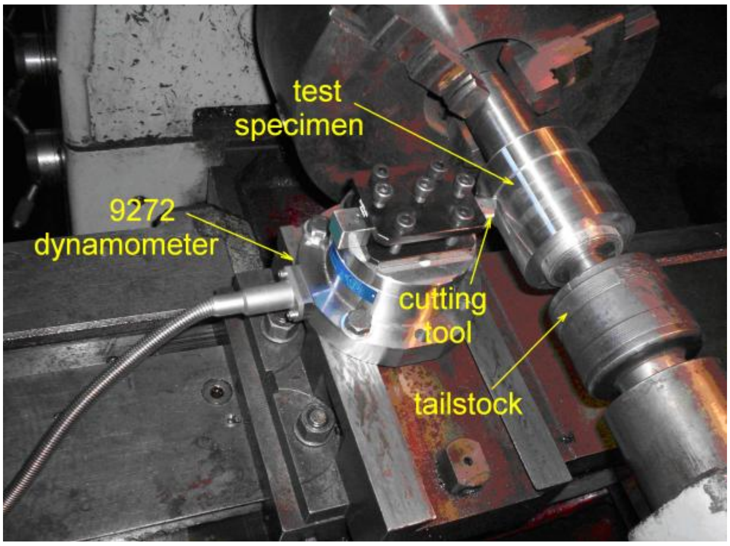

Fig. 4 − Measuring the resultant force and its components.

Were performed three sets of experiments in random order, considering three values of rake (cutting angle) angle and 4 values of the feed, according to data presented in Table 1.

Table 1
Measured Average Values of Components of the Resultant Force

Nr. test	f [mm/rot]	*Cutting conditions*	F_z (F_c) med. value [N]
1.	0.10	γ = +20°(δ_N = 70°); K = 90°; V_c = 89 [m/min]; a_p = 1 [mm];	95.72
2.	0.14		123.57
3.	0.18		149.96
4.	0.22		173.65
5.	0.10	γ = +10°(δ_N = 80°); K=90°; V_c = 95 [m/min]; a_p = 1 [mm];	110.53
6.	0.14		133.31
7.	0.18		163.29
8.	0.22		189.36
9.	0.10	γ = 0°(δ_N = 90°); K = 90°; V_c = 89 [m/min]; a_p = 1 [mm];	149.4
10.	0.14		192.33
11.	0.18		226.73
12.	0.22		258.28

Using the data from Table 2 we studied the evolution of the main component F_z (F_c) for different values of cutting angle δ, obtaining the chart of the Fig. 5.

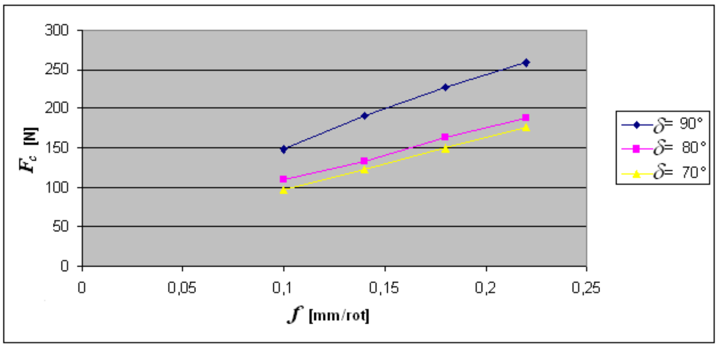

Fig. 5 − Evolution of cutting force $\boldsymbol{F_c}$ depending on cutting angle $\boldsymbol{\delta}$ values for different feed rates.

Examination of the progress of the main component F_c from Fig. 5 reveals the anticipated as normal:

- it diminishing with decreasing the value of cutting angle δ (increasing the value of rake angle γ);
- it growing with increasing the value of feed f.

Applying the logarithm function of values shown in Table 2 for each set of experiments were obtained data from Tables 2, 3 and 4.

Table 2

$\lg\frac{F_c}{b}$ *and* $\lg h, b = 1mm$ *for* δ *= 70°*

h	0.10	0.14	0.18	0.22
lg$h$	-1	-0.8538	-0.74472	-0.65757
$\frac{F_c}{b}$	95.7	123.5	149.9	173.6
$\lg\frac{F_c}{b}$	1.98100	2.09191	2.17597	2.23967

Table 3

$\lg\frac{F_c}{b}$ *and* $\lg h, b = 1mm$ *for* δ *= 80°*

h	0.10	0.14	0.18	0.22
lg$h$	-1	-0.8538	-0.74472	-0.65757
$\frac{F_c}{b}$	110.5	133.3	163.3	189.3
$\lg\frac{F_c}{b}$	2.04348	2.12486	2.21296	2.27728

Table 4

$\lg\frac{F_c}{b}$ *and* $\lg h, b = 1mm$ *for* δ *= 90°*

h	0.10	0.14	0.18	0.22
lgF	-1	-0.8538	-0.74472	-0.6575
$\frac{F_c}{b}$	149.4	192.3	226.7	258.2
$\lg\frac{F_c}{b}$	2.17435	2.28382	2.35551	2.41209

Based on values listed in Tables 2, 3 and 4 the graphs in Figs. 6, 7 and 8 were plotted representing the interpolation line that particularizes the relationship (3) as (4), (5) and (6).

$$\lg\frac{F_c}{1} = 2.73865 + 0.757367 \cdot \lg h \tag{4}$$

$$\lg\frac{F_c}{1} = 2.7257 + 0.689102 \cdot \lg h\,, \tag{5}$$

$$\lg\frac{F_c}{1} = 2.87236 + 0.695403\,\lg h \tag{6}$$

From this relationships were deducted values of the two constants $k_{c1.1}$ and m_c, summarized in Table 5.

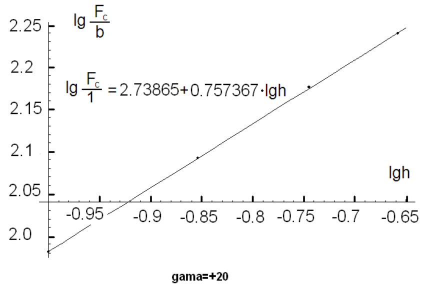

Fig. 6 – Plot of experimental data in logarithmic coordinates for $\delta = 70°$.

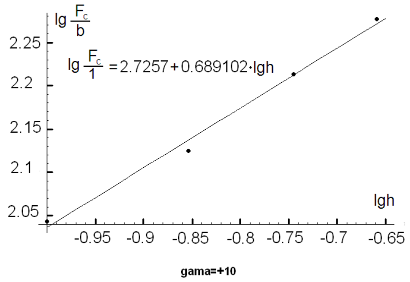

Fig. 7 – Plot of experimental data in logarithmic coordinates for $\delta = 80°$.

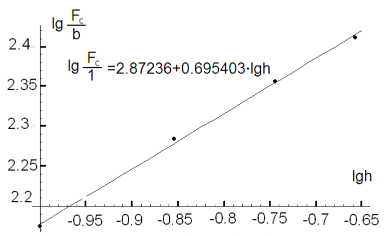

Fig. 8 – Plot of experimental data in logarithmic coordinates for $\delta = 90°$.

Table 5

Calculated values of constants $k_{c1.1}$ and m_c

δ [°]	δ [rad]	$k_{c1.1}$	m_c
90	1.5708	745.35	0.304597
80	1.3962	531.39	0.310898
70	1.2217	547.84	0.242633

3.3. Determining the Influence of Cutting Angle on the Specific Cutting Force

By using the data from Table 5, the Figs. 9 and 10 were constructed, representing the correlations of the constants $k_{c1.1}$ and m_c and cutting angle δ in logarithmic coordinates.

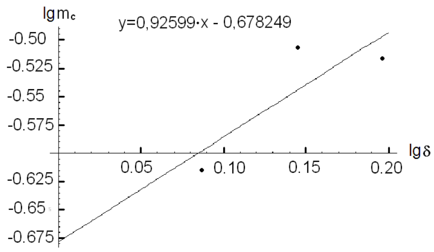

Fig. 9 – The correlation lg$k_{c1.1}$ and lgδ.

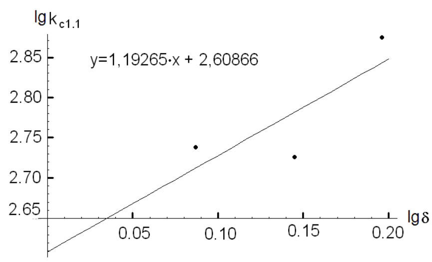

Fig. 10 – The correlation lgm_c and lgδ.

Considering the interpolation lines plotted in Figs. 9 and 10 the final values of the considered constants were calculated as functions of the cutting angle δ:

$$k_{c1.1} = 406.12 \cdot \delta^{1.19} \tag{7}$$

$$m_c = 0.209 \cdot \delta^{0.92}, \tag{8}$$

in both Eqs. (7) and (8), the cutting angle δ must be considered in radians.

4. Discussion

As shown in Fig. 5, the experiments performed with different feed rates demonstrate an increasing of main cutting component F_c, with increasing of cutting angle δ (equivalent to decreasing of rake angle γ).

This result was similar with previous works, who studied the influence of rake angle γ in case of steel cutting (Günaya *et al*., 2005; Haci *et al*., 2006). This situation has been attributed to the influence of rake angle on the tool and chip contact area: small values of rake angle γ (large values of cutting angle δ) cause large contact areas, which lead to raising cutting force.

According the Eq. (1), the main cutting force component F_c depends on chip area A and specific cutting force k_c. Considering also Kienzle equation in form (2), the increasing of specific cutting force k_c can be explained by modification of the unit specific cutting force $k_{c1.1}$ (nominal specific cutting force) and of the exponent m_c.

The graphs from Figs. 9 and 10 confirm this hypothesis, relations (7) and (8) also providing a measure of the influence of the cutting angle δ on specific cutting force.

5. Conclusions

In the course of this paper a method to estimate the influence of a geometric parameter on specific cutting force is presented.

Starting from Kienzle approach, the presented method has two components, an experimental and an analytical one. The experimental components involve measuring the cutting force during the machining of a workpiece using a specific cutting regime. The analytical components involve the use of a graphical and analytical method.

As a result of the present study, two simple analytical expressions having high potential for practical use are presented.

In order to obtain more accurate results the number of experiments should be re-evaluated.

REFERENCES

Croitoru C., Bocăneţ A.-M., Chelariu R., Chicet D., *Evaluation of Machinability of AlCu11 Cast Alloy at Conventional Cutting Speeds*, Bul. Inst. Polit. Iaşi, **LXI (LXV)**, 2, s. Construcţii de Maşini, 131-142 (2015).

Günaya M., Korkut I., Aslan E., Şeker U., *Experimental Investigation of the Effect of Cutting Tool Rake Angle on Main Cutting Force*, Journal of Materials Processing Technology, **166**, 44-49 (2005).

Gonzalo O., Beristain J., Jauregi H., Sanz C., *A Method for the Identification of the Specific Force Coefficients for Mechanistic Milling Simulation*, International Journal of Machine Tools & Manufacture, **50**, 765-774 (2010).

Haci S., Faruk U., Suleyman Y., *Investigation of the Effect of Rake Angle and Approaching Angle on Main Cutting Force and Tool Tip Temperature*, International Journal of Machine Tools & Manufacture, **46**, 132-141 (2006).

Klocke F., *Manufacturing Processes 1: Cutting*, Springer-Verlag Berlin Heidelberg, 2011.

Sekulic M., Jurkovic Z., Hadzistevic M., Gostimirovic M., *The Influence of Mechanical Properties of Workpiece Material on the Main Cutting Force in Face Milling*, Metalurgija, **49**, 4, 339-342 (2010).

Toenshoff H.K., Denkena B., *Basics of Cutting and Abrasive Processes*, Springer-Verlag Berlin Heidelberg, 2013.

EVALUAREA EXPERIMENTALĂ A INFLUENŢEI UNGHIULUI DE DEGAJARE ASUPRA FORŢEI SPECIFICE DE AŞCHIERE

(Rezumat)

Predicţia mărimii forţelor de aşchiere joacă un rol important în determinarea costurilor prelucrărilor mecanice prin aşchiere, în funcţie de materialul semifabricatului, materialul aşchietor, condiţiile de aşchiere şi de geometria sculei aşchietoare.

Din acest motiv s-au dezvoltat numeroase metode de aproximare a forţei de aşchiere, atât analitice cât şi empirice. Având în vedere precizia superioară a modelelor empirice în raport cu cele analitice, lucrarea de faţă propune o metodologie grafo-analitică de evaluare a influenţei unghiului de degajare γ asupra forţei specifice de aşchiere.

În finalul lucrării se prezintă două relaţii simple pentru cele două constante din relaţia forţei specifice de aşchiere, care fac posibilă determinarea precisă a unei valori pentru forţa specifică în interiorul domeniului experimental.