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EXPERIMNTAL INVESTIGATION OF THE INFLUENCE OF CUTTING EDGE REINFORCEMENT ON SPECIFIC CUTTING FORCE

BY

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Abstract. This paper presents an investigation on the influence of cutting edge preparation represented by edge chamfering on cutting efforts. Turning of steel 31MnCrSi11/STAS 791 (60 CrMo3/AFNOR NF) with variable design cemented carbide inserts was performed, cutting forces were measured and values of specific cutting force k_c and unit specific cutting force $k_{c1.1}$ were computed.

Keywords: chamfered edge; specific cutting force; dry machining.

1. Introduction

As it is well known, reinforcement of the cutting edge of cutting tools aims to increase its resistance to bending and to shocks produced especially during roughing operations (Stephenson and Agapiou, 1996, Chen *et al.* 2005).

A common way of reinforcing the cutting edge is to achieve a chamfer defined by an angle γ_f (usually having negative values) and a width f_γ (Fig. 1). The positive effect of the increased resistance of the cutting edge is

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accompanied by negative effect of increased tangential force F_c as is presented in Fig. 2 (Stahl and de Vos, 2014; Kurt and Şeker, 2005).

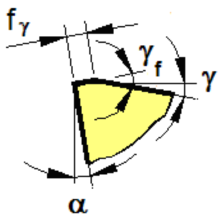

Fig. 1 – Chamfered edge characterization.

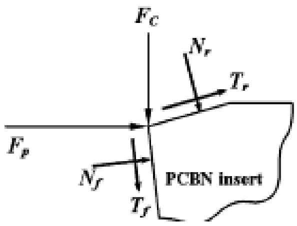

Fig. 2 – Effect of chamfered edge on the load insert.

Influence of chamfer cutting edge on chips formation depends on the ratio in which the chip thickness h and the width of facet f_γ are found, as follows (Sandvik Coromant, 2010):

– when h is smaller than f_γ ($h < f_\gamma$), the facet takes the role of rake face, and the chip is formed similar to case of $\gamma = \gamma_f$ and $f_\gamma = 0$ (Fig. 3);

– when h is greater than f_γ ($h > f_\gamma$) the tangential component of the cutting force F_c is rising.

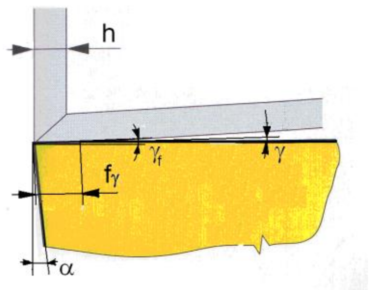

Fig. 3 – Influence of chamfer cutting edge on chips formation.

The influence of the rake value γ on the cutting force is also known. The cutting effort increases when this angle decreases (Shaw, 1997; Günaya *et al*., 2005).

In this study, the influence of edge chamfer width on main cutting force was determined during machining of 31MnCrSi11/STAS 791 (60 CrMo3/AFNOR NF) steel with different values of undeformed chip thickness. As a result of experimental evaluation, the values of specific cutting force k_c and unit specific cutting force $k_{c1.1}$ were calculated.

2. Materials and Methods

Experimental tests were carried out on a cylindrical steel blank 31MnCrSi11/STAS 791 (60 CrMo3/AFNOR NF) having the properties shown below.

Chemical composition [%]		
C	0.34	
Si	1.09	
Mn	0.844	
Cr	1.10	
Mechanical properties		
Hardness (Brinell)		250
Yield strength STAS 791 value [MPa]		830

Fig. 4 – Chemical composition and mechanical properties of experimental samples.

Experiments were carried out on a conventional lathe SNA 560x1500 in dry cutting condition by considering the parameters presented in Fig. 5.

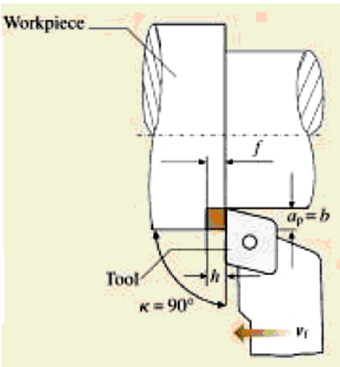

Fig. 5 – Cut and chip variables.

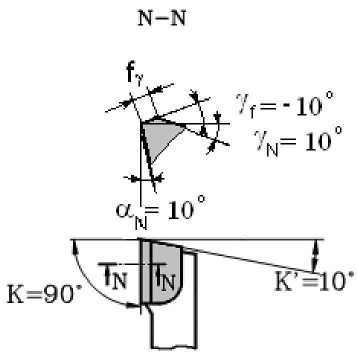

Fig. 6 – Geometric features of the utilized cutting tool.

a *b*

Fig. 7 – Cutting tool: *a* – sharp edge cutting tool; *b* – chamfered edge cutting tool.

Machining tests were conducted by using uncoated carbide P20 tools inserts having different reinforcement as is presented in Figs. 6 and 7.

The others geometric parameters of the considered cutting tools were (Fig. 6).

- 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 = 10°.

A piezoelectric dynamometer Kistler 9272 was used to measure the main component force during the experiments.

Specific cutting force was determined by the graphic-analytical method set out above (Croitoru *et al*., 2015).

3. Results and Discussion

Three sets of experiments were performed in random order, considering three values of facet of chamfered edge f_γ, according to Table 1.

Table 1
Measured Average Values of Components of the Cutting (Main) Force

No. test	f [mm/rot]	Cutting conditions	F_z (F_c) med. value [N]
1.	0.05	γ = +10°; K = 90°; V_c = 75 m/min; a_p = 2 mm; f_γ = 0 mm	326
2.	0.10		540
3.	0.20		972
4.	0.31		1433
5.	0.05	γ = +10°; K = 90°; V_c = 60.47 m/min; a_p = 2 mm; f_γ = 0.12 mm	362
6.	0.10		574
7.	0.20		909
8.	0.31		1458
9.	0.05	γ = +10°; K = 90°; V_c = 68 m/min; a_p = 2 mm; f_γ = 0.4 mm	486
10.	0.10		670
11.	0.20		963
12.	0.31		1392

The first set of experiments (1-4) was performed with the tool having sharp edge (Fig. 7*a*). Values of feed f characteristic of both finishing and roughing operations were considered.

The second set of experiments was carried out with the tool having 0.12 mm width of facet f_γ of the chamfer (Figs. 6 and 7*b*). The feed values *f* were selected so that both the case of chip thickness *h* is less than the width facet f_γ ($h < f_\gamma$) and when is higher than this ($h > f_\gamma$) was considered (Figs. 3 and 6).

The third set of experiments (9-12) aimed to highlighting the manner in which the specific cutting force is influenced by the low values of the rake angle γ. For this reason, the feed values *f* are aimed to achieve the condition that the chip thickness *h* is smaller than the width of facet f_γ ($h < f_\gamma$).

Since the sets of experiments 2 and 3 fulfill the condition $h < f_\gamma$, may be considered that, by these experiments, it can be studied the influence of rake angle on the cutting effort.

3.1. General Evaluation

Using the data presented in Table 2, graphs of evolution of the main component of cutting force F_c (F_z) were plotted by considering its average values recorded for each experiment presented in Fig. 8.

As expected, in all three cases were recorded increases of component F_c with the feed *f* or with the undeformed chip thickness *h*.

The highest rate of increasing of force F_c depending the feed *f* was recorded for the sharp edge ($f_\gamma = 0$), and the lowest for $f_\gamma = 0.4$ mm.

Comparing sets of experiments 2 and 3 may be inferred the rake angle influence on component F_c: F_c component increases when the rake angle γ decreases, a fact reported by Günaya *et al*. (2005), in case of steel turning with PCBN inserts.

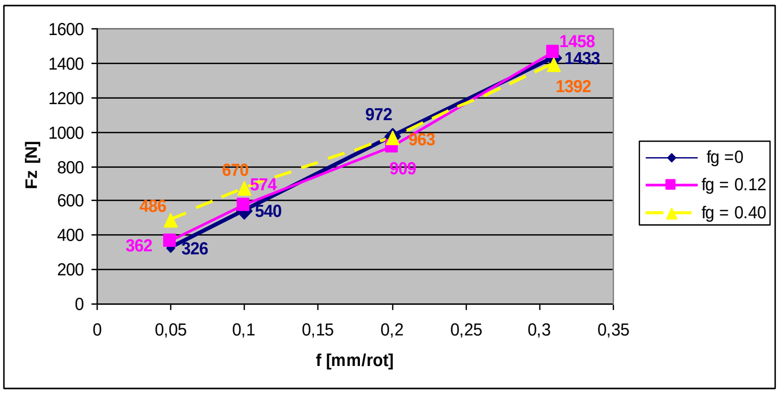

Fig. 8 – Evolution of cutting force *Fc* (F_z) depending on negative facet values for different feed rates.

A facet $f\gamma$ having 0.12 mm leads to a slight increase (about 10%) of the component F_c in the case where the chip thickness is smaller than the width of the chamfer ($h < f\gamma$).

If the thickness h is greater than the width chamfer $f\gamma$ ($h > f\gamma$) the F_c component is increasing, the rate of growing is somewhat less than the sharp edge case ($f\gamma = 0$).

This observation can be useful in finishing operations when cutting force value should be minimized.

3.2. Evaluation of Influence of Cutting Edge Reinforcement on Specific Cutting Force

The Kienzle equation of the main cutting force is:

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

where: k_c is the specific cutting force; $k_{c1.1}$ – the unit specific cutting force; b – the theoretical chip width (Fig. 5); h – the theoretical chip thickness; A – the theoretical chip area; m_c – the exponent of the specific cutting force.

Following the methodology used by (Croitoru *et al.*, 2015), for the three sets of experiments were calculated necessary data by using the values presented in Table 2. The graphs from Figs. 9, 10 and 11 were then plotted.

These charts represent the interpolation line of the Eq. (2) computed for each set of tests:

$$\lg \frac{F_c}{b} = \lg k_{c1.1} + (1 - m_c) \cdot \lg h \tag{2}$$

Table 2
Considered Values of Eq. (2)

No. test	f [mm/rot]	F_c [N]	F_c/b [N/m]	lg$f$	$\lg \frac{F_c}{b^*}$
1.	0.05	326	163	- 1.301	2.2121
2.	0.10	540	270	- 1.0	2.4313
3.	0.20	972	486	- 0.6989	2.6866
4.	0.31	1433	716.5	- 0.5086	2.8552
5.	0.05	362	181	- 1.301	2.2576
6.	0.10	574	287	- 1.0	2.4579
7.	0.20	909	454.5	- 0.6989	2.6575
8.	0.31	1458	729	- 0.5086	2.8627
9.	0.05	486	243	- 1.301	2.3856
10.	0.10	670	335	- 1.0	2.5250
11.	0.20	963	481.5	- 0.6989	2.6826
12.	0.31	1392	696	- 0.5086	2.8426

*$b = a_p = 2$ mm, according to experimental plan

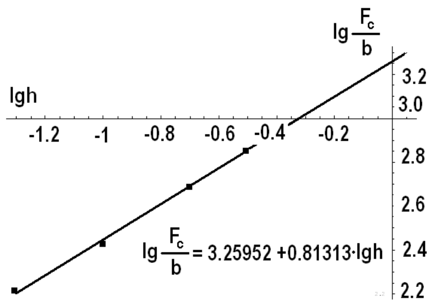

Fig. 9 – Plot of 1st set of experimental data in logarithmic coordinates.

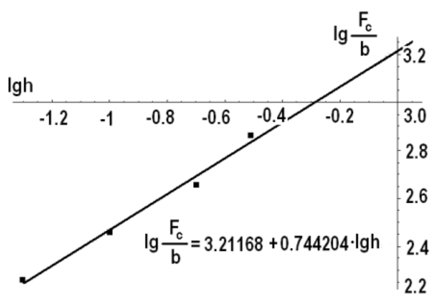

Fig. 10 – Plot of 2nd set of experimental data in logarithmic coordinates.

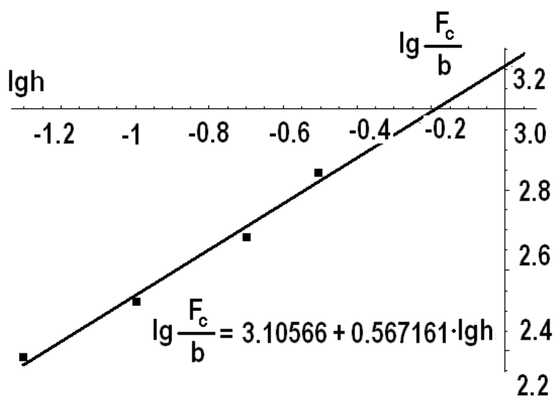

Fig. 11 – Plot of 3rd set of experimental data in logarithmic coordinates.

Table 3
Calculated Values for the Coefficients $k_{c1.1}$ and m_c

	set 1 $f\gamma = 0$ [mm]	set 2 $f\gamma = 0.12$ [mm]	set 3 $f\gamma = 0.12$ [mm]
$k_{c1.1}$ [N]	1816	1628	1275
m_c	0.18687	0.25579	0.43283

By using the relations shown in Figs. 9, 10 and 11, the values of the constants $k_{c1.1}$ and m_c shown in Table 3 were calculated.

Finally, the Eq. (1) and the data from Table 3 were used to calculate the specific cutting force values listed in Table 4.

Table 4
Computed Values of Equation Specific Cutting Force k_c

No. test	f [mm/rot]	f_γ [mm]	k_c [N]
1.	0.05	0	3178
2.	0.10		2792
3.	0.20		2453
4.	0.31		2260
5.	0.05	0.12	3503
6.	0.10		2933
7.	0.20		2457
8.	0.31		2196
9.	0.05	0.40	4662
10.	0.10		3454
11.	0.20		2559
12.	0.31		2117

The specific cutting force values from Table 4 analyze leads to the following observations:

For all three sets of experiments, the increase of feed rate f (equivalent to increasing the thickness h of the chip) led to lower specific cutting force, thus confirming the information known from the literature (Klocke, 2011);

Comparing the corresponding values of sets 1 (tests 1-4) and 2 (tests 5-8) leads to the observation that, if the chip thickness is smaller than the width of chamfer ($h < f\gamma$), there is a slight increase in the specific cutting force value k_c (less than 10%); if the thickness of h values continue to increase over the value of the facet f_γ, the k_c values decrease to give lower values than those calculated in case of sharp edge tool;

The sharp decreasing of the rake angle (tests 9-12) leads to the increasing of the value of k_c; when increasing thickness values h, appears the same trend as in the 2nd set, that is of decreasing of the difference compared to the k_c values reported for the sharp tool;

The use of cutting chamfered cutting edges leads to decreasing of values of specific cutting unit $k_{c1.1}$ and increasing of coefficient m_c values from Eq. (1); it can be concluded that, in case of chamfered cutting edges, increases the influence of chip thickness h (feed f) on specific cutting force and therefore of F_c component;

Considering the same working conditions, changing the cutting edge preparation can lead to a significant change of value of specific cutting unit $k_{c1.1}$; thereby are confirmed the general recommendation not to use this parameter as a criterion of machinability (Toenshoff and Denkena, 2013).

4. Conclusions

The aim of this study was to investigate the effects of cutting edge preparation on cutting forces. The cutting forces were measured in turning of a 60 CrMo3/AFNOR NF steel and were determined the values of specific cutting force and also its specific coefficients $k_{c1.1}$ and m_c. The effects of the feedrates and of the facet of chamfered edge were evaluated.

With reference to the results, the following conclusions can be drawn:

• Using a chamfered cutting edge significantly modify cutting forces and therefore specific cutting force and its coefficients;

• The influence of chamfered cutting edge on the magnitude of cutting force depends on the ratio between chip thickness h (feed rate f) and chamfer width f_γ;

• It was obvious that, for a certain ratio of chip thickness h and width facet f_γ , the cutting efforts start decreasing; this can be useful when cutting force must be minimized;

• When using a chamfered edge increases the influence of feed rate f on the magnitude of cutting forces and therefore of specific cutting force.

REFERENCES

Chen L., El-Wardany T., Nasr M., Elbestawi M.A., *Effects of Edge Preparation and Feed when Hard Turning a Hot Work Die Steel with Polycrystalline Cubic Boron Nitride Tools*, Annals of the CIRP Vol. 55/1/2006.

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, ISSN 1011-2855 (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, ISSN 0924-0136 (2005).

Klocke F., *Manufacturing Processes 1: Cutting*, Springer-Verlag Berlin Heidelberg 2011, ISSN 1865-0899, ISBN 978-3-642-11979-8.

Kurt A., Şeker U., *The Effect of Chamfer Angle of Polycrystalline Cubic Boron Nitride Cutting Tool on the Cutting Forces and the Tool Stresses in Finishing Hard Turning of AISI 52100 Steel*, Materials and Design, **26**, 351-356, ISSN 0264-1275 (2005).

Shaw M.C., *Metal Cutting Principles*, Oxford University Press Inc., New York, 1997, ISBN 0-19-859020-2.

Stahl J.-E., de Vos P., *Metal Cutting Theories in Practice*, SECO TOOLS AB, Lund-Fagersta, Sweden 2014, 02980331, ST20146464 GB, Version 1.1.

Stephenson D.A., Agapiou J.S., *Metal Cutting Theory and Practice*, Marcel Dekker, New York 1996, ISBN 0824795792.

Toenshoff H.K., Denkena B., *Basics of Cutting and Abrasive Processes*, Springer-Verlag Berlin Heidelberg 2013, ISSN 2194-0525, ISBN 978-3-642-33256-2.

*** *Metal Cutting Technology, Technical Guide*, C-2900:7, ENG/01 © AB Sandvik Coromant, 2010.

CERCETĂRI EXPERIMENTALE PRIVIND INFLUENŢA RANFORSĂRII TĂIŞULUI SCULEI ASUPRA FORŢEI SPECIFICE DE AŞCHIERE

(Rezumat)

Microgeometria tăişului unei scule aşchietoare reprezintă un instrument eficient în optimizarea constructiv-funcţională a acesteia.

Eficienţa acestui instrument poate fi dedusă şi prin constatarea marii diversităţi de tipuri şi dimensiuni pe care o oferă firmele producătoare de scule. În ciuda faptului că modificarea microgeometriei tăişului este foarte răspândită la sculele moderne, există puţine informaţii cantitative privind influenţa pe care aceasta o are asupra eforturilor de aşchiere.

Lucrarea de faţă prezintă o modalitate de evaluare a influenţei pe care o manifestă unul dintre parametrii microgeometriei tăişului asupra eforturilor de aşchiere, respectiv asupra forţei specifice de aşchiere.