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THE INFLUENCE OF MECHANICAL PROPERTIES OF WORKPIECE MATERIAL ON THE MAIN CUTTING FORCE IN FACE MILLING

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Preliminary note – Prethodno priopćenje

The paper presents the research into cutting forces in face milling of three different materials: steel Č 4732 (EN 42CrMo4), nodular cast iron NL500 (EN-GJS-500-7) and silumine AlSi10Mg (EN AC-AlSi10Mg). Obtained results show that hardness and tensile strength values of workpiece material have a significant influence on the main cutting force, and thereby on the cutting energy in machining.

Key words: machinability, main cutting force, face milling

Utjecaj mehaničkih karakteristika materijala obratka na glavnu silu rezanja pri čeonom glodanju. U radu su prikazana istraživanja sila rezanja pri čeonom glodanju za tri različita materijala: čelik Č 4732 (EN 42CrMo4), nodularni lijev NL500 (EN-GJS-500-7) i silumin AlSi10Mg (EN AC-AlSi10Mg). Dobiveni rezultati pokazuju da vrijednosti tvrdoće i vlačne čvrstoće materijala obratka imaju veliki utjecaj na glavnu silu rezanja, a time i na ukupno utrošenu energiju rezanja pri obradi.

Ključne riječi: obradivost, glavna sila rezanja, čeono glodanje

INTRODUCTION

There are several criteria for material machinability evaluation, and the most frequently used ones are: tool life (influencing the machining time and production costs), cutting forces (influencing energy consumption), cutting temperatures (influencing tool wear), machined surface quality and chip shape. Based on these criteria, better material machinability is due to: longer cutting tool life, higher productivity (the amount of removed chip), better machined surface quality, lower cutting forces, lower cutting temperatures, and more favourable chip shapes, as long as they have been achieved under the same conditions. In machining diverse materials, under constant machining conditions, diverse cutting forces owe their origin to different physical and chemical properties of the workpiece material. Tensile strength and hardness are typical material properties influencing the main cutting force. There is, of course, a set of other material properties, like the microstructure, crystal grains size and shape, type and amount of impurities and the like, which also exert influence on the main cutting force.

The paper presents the researches into cutting forces in face milling of workpieces made from three different materials (steel for improvement, nodular cast iron, and silumine). To calculate cutting forces, the Kienzle equation constants are determined by the application of the model that enables rational use of laboratory time resources and small workpiece material consumption [1]. From the calculated constants, the main cutting force for adequate cutting conditions may be calculated and thus separate material machinability compared.

MODEL OF CUTTING FORCES

In face milling, the cutting forces exerted by the face milling cutter tooth on the workpiece are changeable in time and space. Figure 1 presents the cutting forces scheme in one-tooth face milling (a shaded area is a chip removed by one tooth per revolution). The paper [1] shows that the main cutting force F_v can be calculated on the basis of measured cutting forces in x and y direction using the following equation:

$$F_v = [-\sin\varphi - \cos\varphi] \cdot \begin{bmatrix} F_x \\ F_y \end{bmatrix} \qquad (1)$$

where φ - angle of cutting point measured from x - axis is anti-clockwise.

The equation (1) can be utilized to draw variation diagrams for the main cutting force F_v during a one-tooth cut. For quality implementation of the Kienzle equation:

$$F_v = b \cdot h^{1-m_v} \cdot k_{v1.1} \qquad (2)$$

it is necessary to know two constants of the workpiece material ($k_{v1.1}$-main specific cutting force related to the cross-sectional area of the cut bxh=1x1=1

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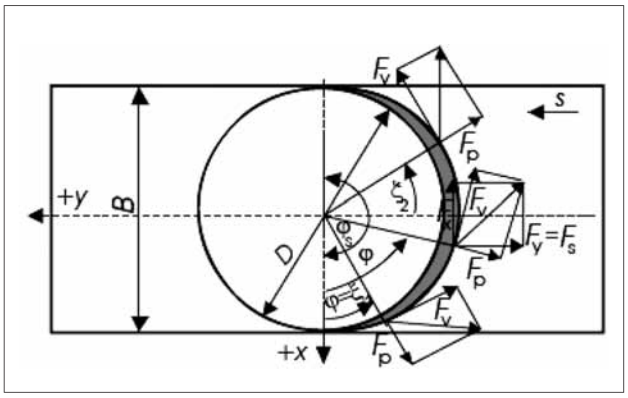

Figure 1 The scheme of cutting forces [2]

mm^2 and exponent 1-m_v). The Kienzle equation constants are machinability parameters of material itself. The undeformed instantaneous chip thickness and width of the cut can be derived as follows:

$$h = s_1 \cdot \sin\varphi \cdot \sin\kappa \quad b = a_p \;/\; \sin\kappa \tag{3}$$

suggesting that there are κ - tool cutting edge angle, s_1 - feed per tooth and a_p - depth of cut.

Since the undeformed chip thickness varies according to the angle of cutting point only one experiment can be performed to obtain straight line F_i/b=f(h), necessary for graphic and analytic determination of the Kienzle equation constants [2].

The power requirements of the milling machine is designed on the basis of the average value of the main cutting force:

$$F_v = b \cdot h_m^{1-m_v} \cdot k_{v1.1} \tag{4}$$

In this equation, h_m is an average undeformed chip thickness which can be approximately calculated by the following equation:

$$h_m = \frac{114{,}6}{\varphi_s^\circ} \cdot \frac{B}{D} \cdot s_1 \cdot \sin\kappa \tag{5}$$

where are: B - cutting width, D - cutter diameter, φ_s - maximal contact angle between the cutter tooth and workpiece.

EXPERIMENTAL PROCEDURE

The experimental work was carried out at the Department of Production Engineering, the Faculty of Technical Sciences in Novi Sad. The machining was conducted on a Vertical-spindle Milling Machine („Prvomajska" FSS-GVK-3). A face milling cutter with ∅80 mm diameter („Jugoalat" G.707.1), with cemented carbide inserts („Sintal" type P25 for steel and nodular cast iron and type K10 for silumine) with tool cutting edge angle κ=75° and rake angle γ=0°, was used as a tool. All of the experiments were conducted with one insert without coolant, except for machining silumine when, due to intensive adhesion chip for insert, petroleum was used. The analysed materials are: steel Č4732, nodular cast iron NL500 and silumine AlSi10Mg.

During the experiments, cutting forces were measured using a three-force components Kistler dynamometar (the model 9257A) and also sampled using a PC based data acquisition system with LabVIEW software [3]. The experiment conditions and research into mechanical properties of material are summarized in Table 1. The selection of cutting conditions are closely connected to the cutting tool and workpiece material. The chemical composition of the investigated materials is shown in Table 2. Figures from 2 to 4 show their microstructure.

The quenched and tempered microstructure of the steel Č4732 was determined by the metallographic research, Figure 2.

The microstructure of the nodular cast iron is composed of ferrite, perlite and graphite nodule, Figure 3.

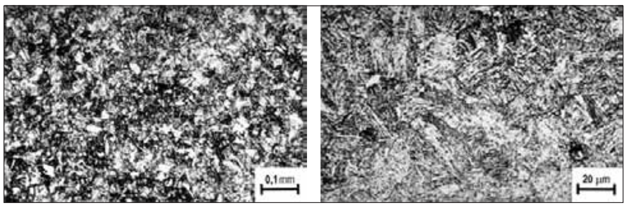

Figure 2 The microstructure of steel Č4732

Table 1 **Experiment conditions and mechanical properties of materials used during machinability test**

Workpiece material		Tensile strength R_m /MPa	Hardness /*HB*	Cutting tool material	*v* / m/min	s_1 / mm/tooth	a_p /mm
Code in JUS	**Code in DIN**						
Č4732	42CrMo4	975	265	HM P25	89,17	0,281	1
NL500	GGG-50	495	170	HM P25	89,17	0,281	1
AlSi10Mg	G-AlSi10Mg	85	49	HM K10	281,48	0,281	1

Table 2 **The chemical composition of materials used during machinability test**

Material	Chemical composition / wt. %											
	C	**Si**	**Mn**	**S**	**P**	**Cr**	**Mo**	**Ni**	**Cu**	**V**	**Fe**	**Mg**
Č4732	0,40	0,427	0,497	0,042	0,039	0,914	0,183	0,35	0,17	0,01	-	-
NL500	3,50	2,67	0,40	0,012	-	0,05	-	-	-	-	-	-
AlSi10Mg	-	9,03	0,282	-	-	-	-	-	0,069	-	0,46	0,104

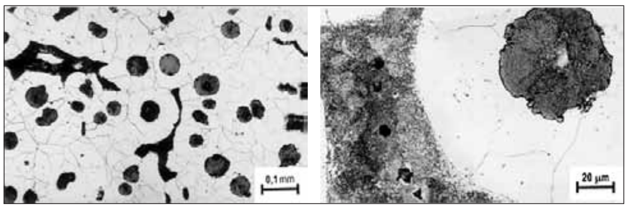

Figure 3 The microstructure of nodular cast iron NL500

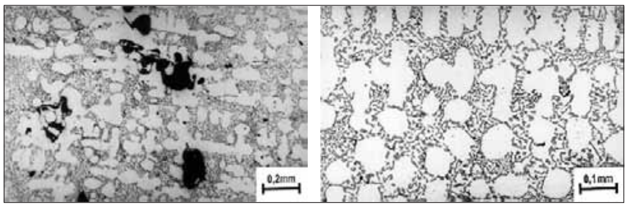

Figure 4 The microstructure of silumine AlSi10Mg

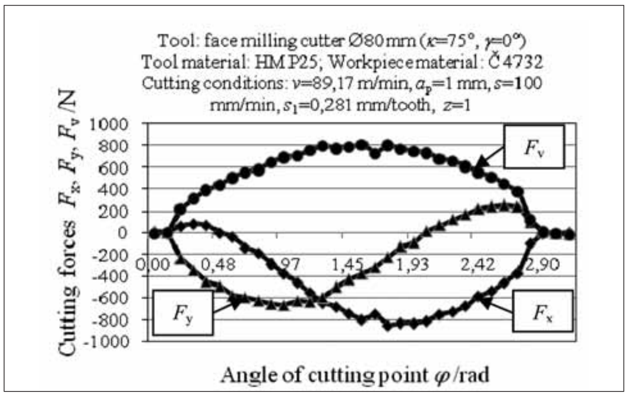

Figure 5 Cutting forces variation vs. tooth position

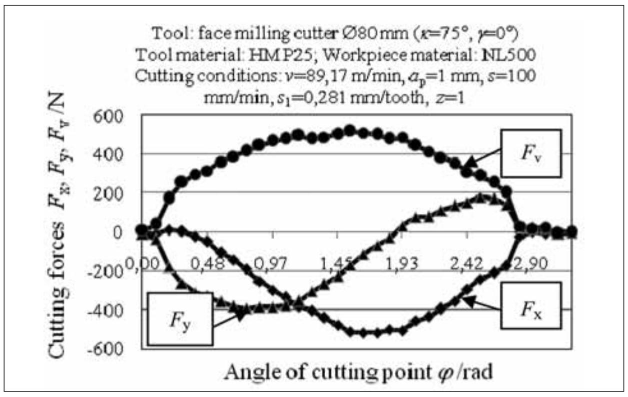

Figure 6 Cutting forces variation vs. tooth position

There are also micro-cavities of irregular shapes, as well as non-homogenity in perlite amount (micro-cavities can be observed in perlite as well).

Figure 4 presents modified silumine comprising of α solid solution and granular eutectic. Micro-cavities and the dendrite orientation of the microstructure can be observed.

EXPERIMENTAL RESULTS

Figures 5 to 7 present diagrams of variations in orthogonal cutting forces and main cutting force, derived from the equation (1) for face milling of the tested materials.

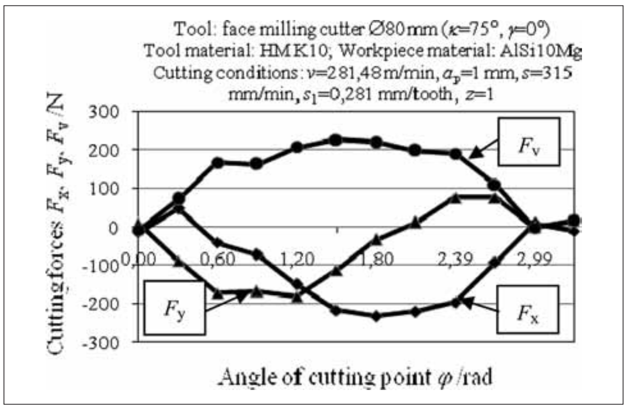

Figure 7 Cutting forces variation vs. tooth position

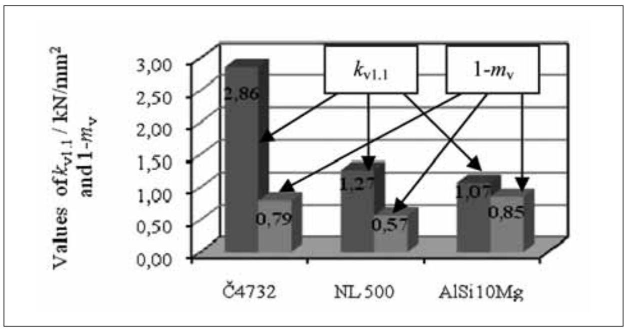

Figure 8 Empirically determined Kienzle constants

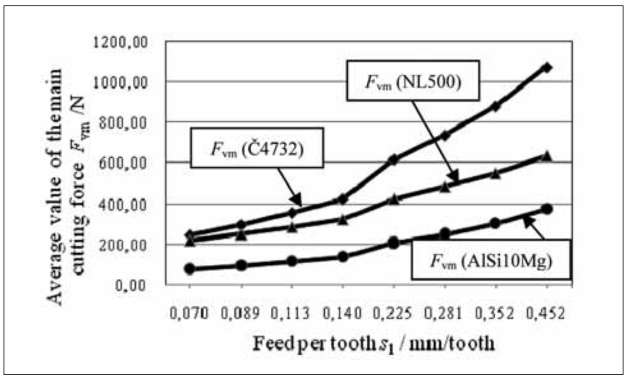

Figure 9 Variation F_{vm} vs. feed per tooth

Determined values of the main specific cutting force $k_{v1.1}$ and exponent of the Kienzle equation 1-m_v are shown in Figure 8.

Based on the constants from Figure 8 and the conditions from Figure 1 (B=D, $\varphi_s=\pi$), the average value of the main cutting force for different feed per tooth can be calculated by utilizing the equation (4), Figure 9.

The average value of the main cutting force with reference to hardness of analysed materials (e.g. for feed per tooth s_1=0,281 mm/tooth, accordingly for average undeformed chip thickness h_m=0,173 mm and width of the cut b=1,035 mm), is presented in Figure 10. It is obvious that the hardness value of workpiece material has a significant influence on the value of the main cutting force in face milling.

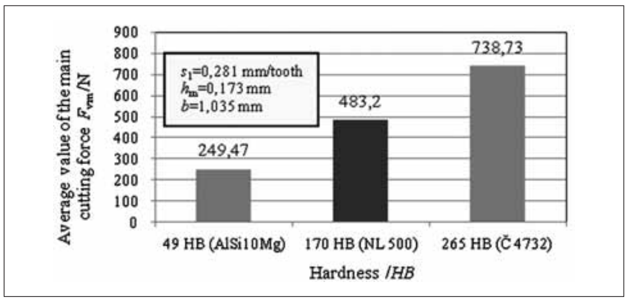

Figure 10 Variation F_{vm} vs. hardness *HB*

CONCLUSION

Mechanical properties of workpiece material are important factors affecting machining conditions. Regarding low cutting forces, low values of hardness and tensile strength usually provide better machinability. This investigation has shown that hardness and tensile strength of the workpiece material have a significant influence on the main cutting force in face milling, and thereby on the cutting energy in machining.

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Note: The responsible translator for the English language is Ksenija Mance, Senior Lecturer at the Faculty of Engineering, Rijeka, Croatia.