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INVESTIGATION OF THE MACHINING PROCESS OF SPHEROIDAL CAST IRON USING CUBIC BORON NITRIDE (CBN) TOOLS

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This paper presents the experimental results of the turning of spheroidal iron (EN-GJS-500-7 grade) using L-CBN tools. The cutting process can be classified as a High Performance Cutting (HPC) due to a relatively high material removal rate of about 190 cm^3/min. The investigations performed include fundamental process quantities and machined surface characteristics, i.e. componential cutting forces, specific cutting energy, average and maximum values of cutting temperature as well as temperature distribution in the cutting zone, tool wear progress visualized by appropriate wear curves and 2D/3D surface roughness parameters.

Key words: spheroidal cast iron, CBN tool, cutting force, cutting temperature, surface roughness

INTRODUCTION

Recently, advanced manufacturing has continued to apply materials with specific service properties. In particular, machine building, automotive and energy/wind power industries consume more ductile irons including nodular cast iron/spheroidal cast iron (NCI/SCI), compacted graphite iron (CGI) and austempered ductile iron (ADI) grades. This trend can be explained in terms of their higher mechanical strengths keeping good yield (plasticity) and fatigue strengths [1]. According to the machinability rating, these irons are classified as difficult-to-machine materials. Their machinability rates are comparable to high-strength alloy steels, for example P-F SCI with AISI 4140 steel [2]. As a result, they need special technological routines to be machined efficiently. On the other hand, cutting tool manufactures do not yet recommend appropriate tooling and cutting conditions [3]. The machining of SCI needs, due to characteristic two-phase microstructure with globular graphite inclusions and high ductility, more wear resistant cutting tool materials such as multilayer coated carbides, uncoated and coated silicon nitride ceramics Si_3N_4, (coated with Al_2O_3/TiN), SIALON and L-CBN depending on iron grade and machining conditions [4].

Because previous cutting experiments when machining P-F SCI material with coated and uncoated silicon nitride cutting tools indicated rather low tool lives of maximum several minutes [3-5] this study was performed using L-CBN tools. It is obviously known that CBN tools are capable of machining EN-GJS-500-7 iron with distinctly higher cutting speed up to about 500 m/min. Moreover, the material removal rate (MRR) can be increased considerably [6]. This experimental study is focused on the cutting performance and surface quality in terms of componential cutting forces, cutting temperature distribution in both primary and secondary zones and obtainable surface roughness. The cutting tests were performed under orthogonal (O) and semi-orthogonal (S-O) conditions with variable cutting speed between 100 and 400 (500) m/min, feed rate varying between 0,04 and 0,24 mm/rev and depth of cut equal to 3,3/0,8 (O/S-O) mm.

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EXPERIMENTAL METHODOLOGY

Workpiecematerials

The workpiece material was the pearlitic-ferritic spheroidal (nodular) iron (PF-SCI), EN-GJS-500-7 grade.

Table 1 **Chemical composition of EN-GJS-500-7 iron / wt. % [4]**

C	Si	Cu	Mg	Mn	P	S
3,78	2,46	0,01	0,05	0,32	0,038	0,065

Its microstructure contains approximately 50 % pearlite, 40 % ferrite and 10 % graphite. The basic mechanical properties are: R_m = 500 MPa and hardness of 175 HB. Chemical composition of the SCI machined is specified in Table 1.

Cutting tool and cutting conditions

The machining of SCI workpieces was performed using cutting inserts of N123H1040004S01025 type mounted in LF 123H25–2020BM type holder and triangular TNGA160408S01030 inserts clamped in PTGNL 2020K16 holder for orthogonal and semi-orthogonal operations respectively. CBN cutting inserts with low content of CBN (L-CBN), grade CB 7015 according to Sandvik designation, were used [7]. The measured radius of the cutting edge was equal to 7 mm. The chamfer angle was γ_{ch}=- 25 ° and its length was l_{ch}= 100 mm.

Cutting experiments were divided into the two series:

Series I under orthogonal conditions: a) with variable cutting speed of 100, 160, 240, 280, 320, 400 m/min, constant feed rate of 0,12 mm/rev and constant depth of cut of 3,3 mm, and b) with constant cutting speed of 240 m/min, variable feed rate of 0,04, 0,08, 0,12, 0,16, 0,2 0,24 mm/rev and constant depth of cut of 3,3 mm.

Series II under semi-orthogonal with variable cutting speeds of 100, 160, 240, 320, 400, 480 m/min, two feed rates of 0,08 and 0,12 mm/rev and constant depth of cut of 0,8 mm. During experiments all trials were repeated three times.

Measurement techniques

All machining tests were carried out on a CNC turning centre - Transmab 450TD. A thin disk was orthogonally machined with radial tool engagement as shown in Figure 1. In the first part of experiments the cutting F_c and feed F_f forces were measured by means of the Kistler's commercial piezoelectric dynamometer, model 9257A included in the measuring circuit shown in Figure 1. Force signals were transmitted in on-line mode to the Kistler 5070 amplifier and a PC with National Instruments LabView 6i software to acquire and analyze. The generated signals were recorded with the frequency of 1 000 Hz.

Parallel to force measurements, the temperature distribution in the cutting zone was recorded using the infrared technique. In this case, IR-CCD set-up (Figure 1) consists of an infrared camera ThermaCAMTM Phoenix, Flir System, special lens and protective window. The CCD-IR camera used can register thermal images with the resolution of 320 × 255 pixels, which is enough to obtain high quality thermal maps. The cutting temperatures were determined using the emissivity curve (shown in Figure 1) obtained previously for the nodular cast iron (NCI) machined in the temperature range of 50 °C ÷ 600 °C. The calibration procedure is described in details in Ref. [5].

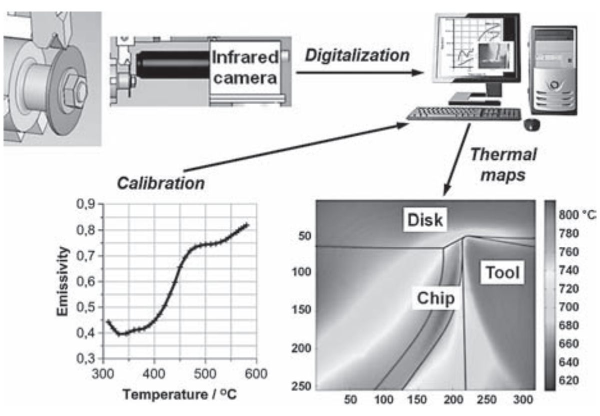

Figure 1 Scheme of IR thermal mapping technique

The flank and rake surfaces of CBN inserts were successively examined during tool wear period using a LOM Leica equipped with a CCD camera. The images obtained were digitized using special graphical program. After turning the surface profiles/ topographies were recorded using a profilometer and the 2D and 3D roughness parameters were determined.

EXPERIMENTAL RESULTS

Components of the resultant cutting force

Figure 2 shows the influence of the cutting speed and feed rate on the values of the cutting F_c and feed F_f forces acting on the CBN tools. The predicted values of both forces are maximum 5 % lower or higher than experimental results.

Figure 2 shows that F_c and F_f forces decrease slowly when the cutting speed increases. For instance, the maximum value of F_c force of about 850 N was recorded for the minimum cutting speed of v_c = 100 m/min. In turn, the minimum value of F_c force of about 750 N corresponds to the cutting speed of v_c = 400 m/min. The values of the feed force (course #2) are visibly lower. For example, the maximum F_f force of about 620 N was also recorded for the cutting speed of v_c = 100 m/min. It can be observed in Figure 2 that the difference between values of F_c and F_f forces is about 200 N.

It can also be seen from Figure 2 that both forces increase when feed increases up to 0,24 mm/rev. For example, the effect is that force Fc increases from about

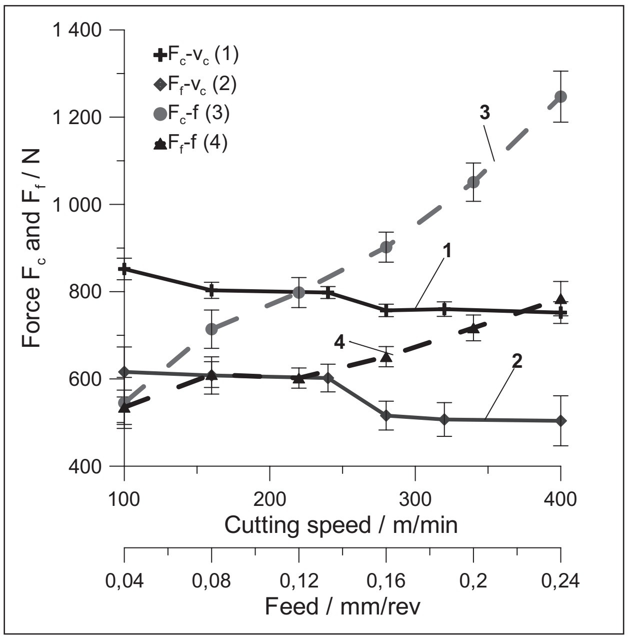

Figure 2 Influence of cutting speed and feed rate on F_c and F_f forces

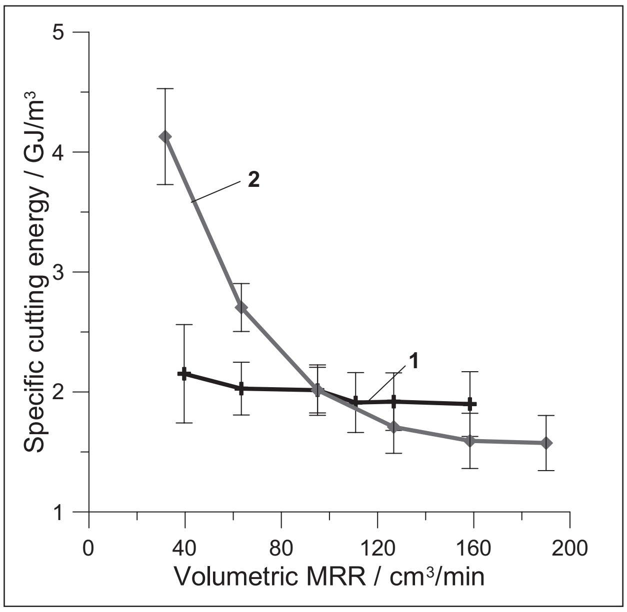

Figure 3 Specific cutting energy vs. volumetric machining rate: 1-influence of cutting speed, 2- influence of feed rate

550 N to 1245 N. In the case of F_f local minimum value appears at the feed of 0,12 mm/rev. Another characteristic observation is that for the feed of 0,04 mm/rev the values of F_c and F_f forces are comparable, probably due to intensive friction.

Figure 3 shows the energetic characteristic of the machining process performed in terms of the relationship between the specific cutting energy (SCE) and volumetric machining rate (Qv). It is evident in Figure 3 that the obtainable machining rate is about 190 cm³/min.

Cutting temperature

Figure 4 presents exemplarily colored thermal maps recorded by means of thermographic technique. In order to localize the thermal fields, the curled chip and the CBN insert are also captured in Figure 4. It can be noted in Figure 4a-c that the localizations of both average and maximum temperatures within the cutting zone were distinguished for different cutting speeds.

The areas with higher temperatures in the CBN inserts are probably due to the fact that thermal conductivity of CBN is relatively high [1]. In previous investigations with coated nitride ceramic tools this phenomenon was not observed [5].

One particular finding from the thermal analysis shown in Figure 4 is that the differences between maximum and average values of temperatures measured in the cutting zone are not distinct. As a result, in this study the average contact temperature changes in the range of t = 412 – 512 °C, (see Figure 5) whereas its maximum value varies between t_{max} = 426 – 541 °C. The maximum difference between maximum and average temperatures of about 40 °C was recorded for the maximum cutting speed of v_c = 400 m/min. Surprisingly, low temperatures recorded in the cutting zone result from the specific chip formation of the two-phase material in which graphite inclusions facilitate its decohesion. In fact, a high-velocity stream of small chips was formed during the turning of SCI material. Moreover, this specific effect can result from substantial decreasing of the tool-chip contact length/area and concentration of the heat within very small area in comparison to steel machining [5].

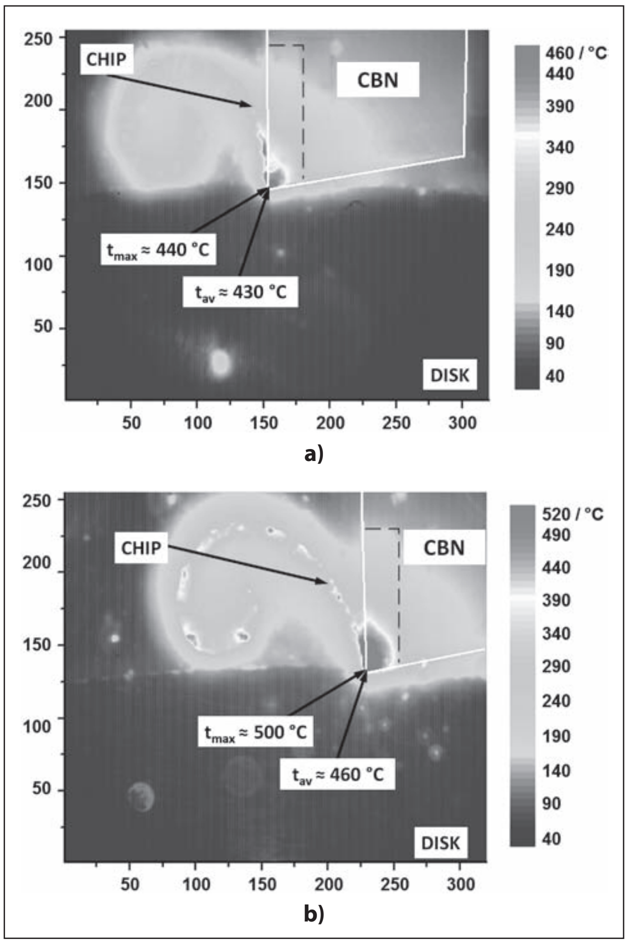

Figure 4 Thermal maps for orthogonal cutting for different cutting speeds: (a) v_c = 280 m/min, (b) v_c = 400 m/min keeping constant f = 0,12mm/rev and a_p = 3,3 mm

As shown in Figure 5, the increase of cutting speed from 100 to 400 m/min causes the average temperature to increase linearly of about 50 °C. When considering the influence of feed, the temperature plot tends to display

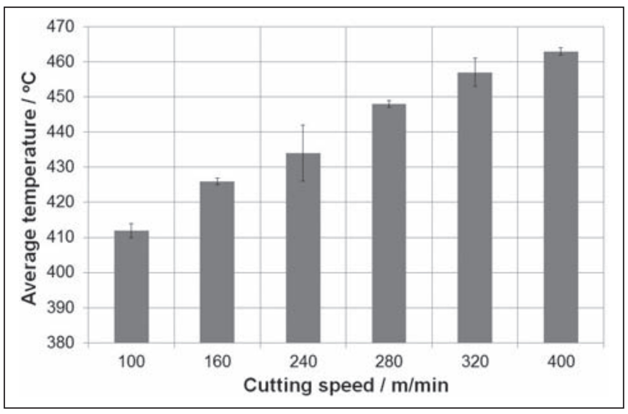

Figure 5 Influence of cutting speed on the cutting temperature

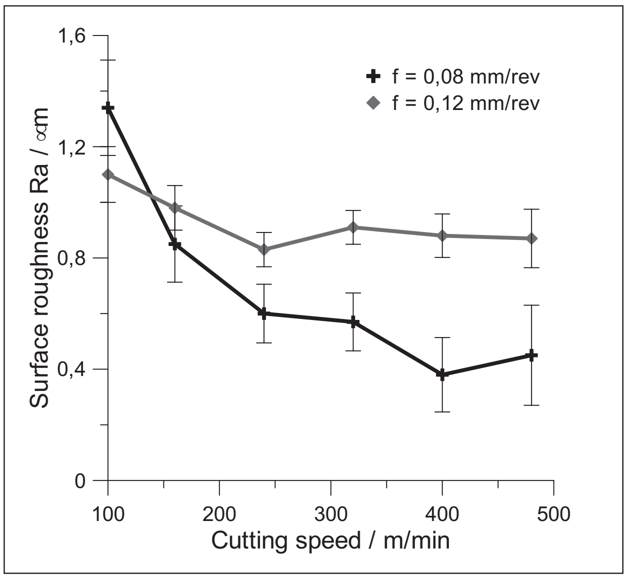

Figure 6 Influence of cutting speed on the roughness average Ra

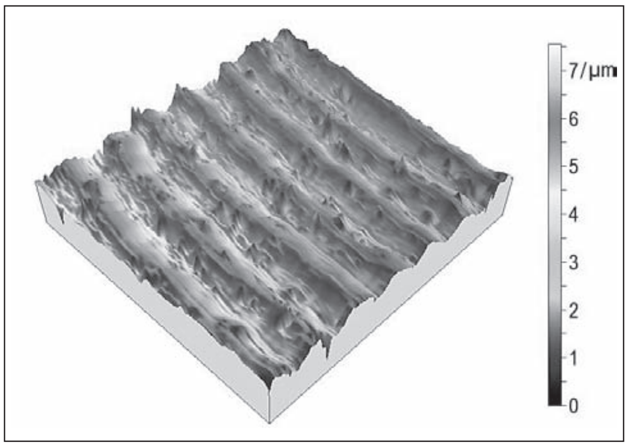

Figure 7 Surface topography at different magnifications generated with v_c = 400 m/min, f = 0,08 mm/rev and r_ε = 0,8 mm. Sa = 0,49 µm, Sz = 13,2 µm, Sp = 5,43 µm, Sku = 7,82, Ssk = -0,67

the minimum value of 430 °C at the feed of 0,12 mm/rev. This fact can be explained in terms of the corresponding values of the specific cutting energy, shown in Figure 3. In fact, for the feed of about 0,12 mm/rev the value of e_c approaches 1,9 GJ/m^3. It can also be noticed that the computation accuracy depends on the errors in the determination of SCI emissivity versus temperature.

Surface roughness and surface topography

Figure 6 presents the influence of the cutting speed on the surface roughness average Ra. For the cutting speeds of 240 - 480 m/min and feed rate of f = 0,08 mm/rev the Ra value decreases from 0,6 to 0,38 µm. The maximum value of Ra = 1,34 µm was measured for feed of 0,08 mm/rev and cutting sped of v_c = 100 m/min, which is typically observed in machining practice [1]. At a higher feed rate of f = 0,12 mm/rev, the Ra parameter varies in the range of Ra = 1,1 - 0,83 µm. In this case, the trend showing lower surface roughness with higher cutting speed is less pronounced.

In addition, Figure 7 shows surface topography obtained at the maximum cutting speed of 400 m/min and low feed rate of 0,08 mm/rev. In general, surfaces with regular asperities and good bearing properties (negative Ssk values) are generated. At higher feed rate of 0,12 mm/rev small craters resulting from the removal of graphite inclusions are observed.

CONCLUSIONS

1) The cutting and feed forces decrease when machining with higher cutting speeds and increase non-linearly when feed rate increases. The local minimum of the specific cutting energy corresponds to the minimum value of feed force.
2) The variations of the average tool-chip contact temperature under machining conditions employed are not so distinctive as in the steel machining. Maximum temperature in the cutting zone of 510 °C was recorded for f = 0,24 mm/rev and v_c = 240 m/min. On the other hand, the minimum temperature of 410 °C corresponds to cutting speed of v_c = 100 m/min.
3) SCI machining with high cutting speeds visibly improves the surface finish. In this study, the minimum value of Ra roughness parameter of about 0,4 µm was recorded for v_c = 400 min and f=0,08 mm/rev. Under these machining conditions defect-free surfaces with regularly distributed feed marks are produced.

REFERENCES

[1] Grzesik W.: Advanced machining processes of metallic materials. Elsevier, Amsterdam 2008.
[2] Graham D.: Machining cast iron. Manufacturing Engineering, 136(2006) 2, www.sme.org.
[3] Klocke F., Klöpper C., Lung D., Essig C.: Fundamental Wear Mechanisms when Machining Austempered Ductile Iron (ADI). Annals of the CIRP, 56(2007) 1, 73-76.
[4] Małecka J., Grzesik W., Kowalczyk D., Kiszka P.: Image analysis of wear effects when machining nodular cast iron with silicon nitride tools. Tribologia, 42(2011) 2, 71-84
[5] Schneider J., Richter G.: Eine Keramik für viele Fälle. Werkstatt und Betrieb, 139(2006) 6, 51-55.
[6] Byrne G., Dornfeld D., Denkena B.: Advancing cutting technology, CIRP Annals-Manufacturing Technology, 52(2003) 2, 483-507.
[7] Machining Handbook, Sandvik Coromant, 2010.

Note: The responsible for English language is the lecturer from Opole University