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# DEVELOPMENT IN MACHINING TECHNOLOGY

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Edited by  
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This study aims to provide the recent advances in machining for modern manufacturing engineering, especially CNC machining, modern tools and machining of difficult-to-cut materials, optimization of machining processes, application of measurement techniques in manufacturing, modeling and computer simulation of cutting processes and physical phenomena.



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## DEVELOPMENT IN MACHINING TECHNOLOGY

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## **PREFACE**

Machining is one of the most popular technique to change shape and dimensions of the objects. Machining operations can be applied to work metallic and non-metallic materials such as ceramics, composites, polymers, wood.

Cutting tools have been used since ancient times to remove excess material from forgings and castings. Nowadays, metal cutting became one of the primary manufacturing processes for finishing operations. In the last few years we have observed a rapid development in automation of manufacturing processes, especially in automatic control systems. Progress in cutting stimulates a significant increase in the metal removal rate and achieving high accuracy in terms of dimensions and shape of machine parts. New materials, which play the key role here, are used to produce cutting tools.

To meet today's high demands concerning accuracy and efficiency of the manufacturing process of machine parts, it is necessary to use computer methods for designing of technological processes.

This study aims to provide the recent advances in machining for modern manufacturing engineering, especially CNC machining, modern tools and machining of difficult-to-cut materials, optimization of machining processes, application of measurement techniques in manufacturing, modeling and computer simulation of cutting processes and physical phenomena.

Wojciech Zębala

## **PART 1**

### **Machining of Difficult-To-Cut Materials**

## Chapter 1.1

# INVESTIGATION OF HARDENED TOOL STEEL TURNING WITH CBN INSERTS

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**Abstract:** *The paper presents examples of hard turning applications, its comparison with grinding and results of hard turning researches on cold work tool steel with the cubic boron nitride tools. The influence of cutting conditions and material hardness on cutting forces, surface roughness, sequences of chip formation and thermograms are presented.*

**Keywords:** *hard turning, tool steel, cutting forces, surface roughness, CBN, high-speed camera, IR camera*

### 1. Introduction

Many metal machining fields attempt to increase productivity of processes, quality of the products, flexibility and environmental performance of production processes. One of those is hard cutting. With huge development in the area of super-hard materials of tools, it is possible to machine hardened materials with hardness 60HRC or even more.



Fig. 1. Hard turning [Monforts]

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Hard machining, also known as a hard part machining or hard cutting, is the machining process of metal parts, harder than 45 HRC, with the cutting tool of a geometrically defined cutting edge. Nowadays hard machining is a finishing or semi-finishing metal cutting process with accuracy and surface roughness similar to grinding. Roughing machining of hardened parts is possible but in some cases it is not economic choice. Hard machining is divided into hard turning, hard milling and hard drilling. The most popular of these is hard turning, which is an alternative for grinding of shafts, bushes or discs, Fig. 1. Usually machined work pieces are made of various types of hardened alloy steels (bearing steels, cold- and hot work tool steels and high speed steels), hardened cast irons, sintered carbides, metal-ceramic composites and superalloys. Hard cutting requires special tool materials, with high wear-resistant and high hardness at elevated temperatures. That's why wedges of the tools are usually made of cermetals, ceramics and cubic boron nitrides (CBN), Fig. 2. Sometimes as a tool material also are used: polycrystalline diamond, sintered carbides and silicon nitrides. Polycrystalline cubic boron nitride is characterized by extraordinary hardness at elevated temperatures and compressive strength with good fracture toughness. Diamond is not suitable for machining ferrous materials due to diffusion wear of the tool, especially intensive at elevated cutting temperatures [1] [2] [3].

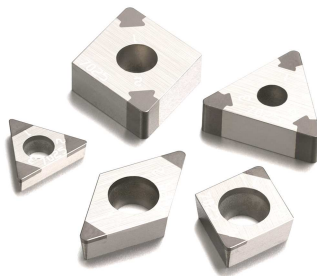


Fig. 2. CBN inserts for hard turning made of CBN 7025 [Sandvik Coromant]

Basically the hard turning process is a high speed, low feed and low depth of cut finishing or semi-finishing process. The cutting speed reported, in various works, is in the range 100-250 m/min [4] [5] [6] [7] [8]. When the cutting speed is higher, stability problems can occur. Feed rate belongs to the range 0.05-0.15 mm/rev and depth of cut is not higher than 0.2mm [5] [6] [7] [9]. Some of researchers [4] have reported the higher depth of cut. Cutting parameters, work piece materials and materials of tools presented in various works are given in Table 1.

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The limitations and disadvantages of hard machining are not usually presented in commercial papers: tool cost per machined part can be significantly higher in hard machining in comparison to grinding; the best solution during hard turning is small ratio of length-to-diameter; usually special rigid machine tools are required to achieve the good results; machine rigidity strongly influences on part accuracy [8] [10].

Table 1. Cutting parameters, work piece and cutting tool materials used by various authors

Author	Work piece material	Rockwell hardness	Tool materials	Cutting parameters
Aouici, Chaoui, Mabrouki, Rigal, Yaltese [4]	AISI H11 100Cr6	40;45;50HRC 60HRC	57% CBN + 35% Ti(C, N)	$v_c=120-240$ m/min $f=0.08-0.16$ mm/rev $a_p=0.15-0.45$ mm $v_c=90-350$ m/min $f=0.08$ mm/rev $a_p=0.1-1$ mm
Byrne, Denkena, Dornfeld [5]	100Cr6	61HRC	CBN	$v_c=140$ m/min $f=0.08$ mm/rev $a_p=0.2$ mm
Coelho, Elbestawi, Ng [6]	AISI 4340	52HRC	CBN+TiAlN coating; without coating	$v_c=150$ m/min $f=0.07$ mm/rev $a_p=0.2$ mm
Dobrzyński, Orłowski [7]	14NiCrMo13- 14	60HRC hardened and carburized	50% CBN + TiCN+Al <sub>2</sub> O <sub>3</sub>	$v_c=130-160$ m/min $f=0.06-0.15$ mm/rev $a_p=0,04$ mm
Schuman [9]	X38CrMoV5-1 100Cr6 S-6-5-2	52HRC 60-62HRC 65HRC	CBN	$v_c=40-400$ m/min $v_c=40-250$ m/min $v_c=45-200$ m/min $f=0.05$ mm/rev $a_p=0.05$ mm

## 2. Comparison of hard turning and grinding

The graph in Fig. 3 presents two different ways of machining hardened parts such as shaft, bush or disc.

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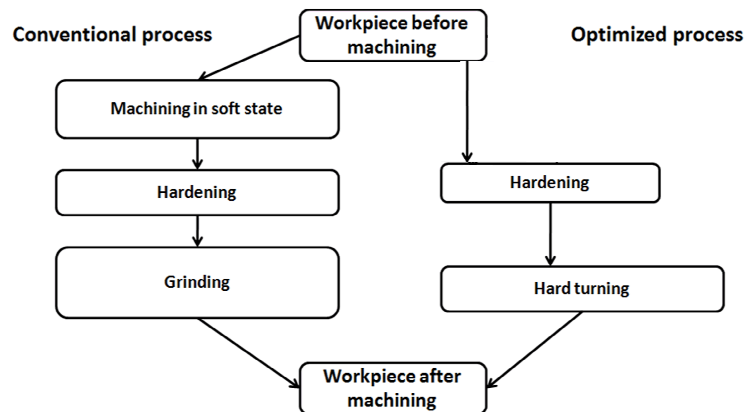


Fig. 3. Conventional and proposal of optimized processes of machining hardened parts

On the left side in Fig. 3 there is an example of conventional machining process and on the right side – proposal of optimized solution. The optimized process, including hard turning, is shorter and enables to avoid some operations because of the higher rate of material removal. It helps to reduce the production time, the number of machine tools and the number of processes. In the optimal process machining in soft should be omitted, but if it is required then machining in soft and hardened state can be done on the same machine tool.

Grinding has been a typical process of machining of the hardened metal parts. Table 2 presents comparison of some energetic factors and surface layer properties of a hardened shaft made of bearing steel 100Cr6 [11]. As we can notice, cutting power and specific cutting energy are much lower in case of hard turning. It means that the energy consumption of hard turning process is much lower because of higher rates of metal removal, lower range of cutting speed and lower heat energy generated in the shear zone. Some additional differences should be mentioned: generally, grinding machines and equipment are more expensive, multiple machining operations in one set-up are more flexible in case of turning. Tool change time is shorter and complex contour can be performed in case of hard cutting. Macro-, micro-geometry and physical properties of the surface depend on the stiffness of machined part, machine tool, cutting tool and work piece. Better quality and efficiency of machining process can be obtained through the connection of hard turning with the high precision of grinding processes. During hard turning metal chips can be easy recycled, coolant is not required or cold air can be used. Lathes are

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safer for users than grinding machines. Damages of grinding wheels are more dangerous than damages of cutting tools [1] [2] [3] [10] [12] [13] [14] [15].

Table 2. Comparison of energetic and geometric properties (bearing steel 100Cr6)[11]

Factor		Hard turning	Grinding	
Tool		CBN insert	CBN grinding wheel	Al <sub>2</sub> O <sub>3</sub> grinding wheel
Cutting parameters	$l_s=b_s=15$ mm $d=16$ mm	$v_c=160$ m/min air	$v_s=58$ m/s emulsion 10%	$v_s=45$ m/s emulsion 5%
Cutting force	$F_c$ [N] $F_c'$ [N/mm]	$F_c=34,1$	$F_c'=2,25$	$F_c'=0,44$
Cutting power	$P_e$ [W]	90	1960	297
Cutting energy	$e_c$ [J/mm <sup>3</sup> ]	6,8	65,3	99
Surface roughness	$R_z$ [μm]	0,5÷0,7	0,7	0,4÷0,5
Max. height of waviness	$Wp$ [μm]	0,8÷1,1	1,1	0,7÷1,1
Roundness deviation	$\Delta o$ [μm]	0,2÷0,25	0,9	0,15÷0,4
Cylindricity deviation	$\Delta w$ [μm]	0,6÷0,9	1,4	0,3÷1,1

In the Fig. 3-a many-roller metal tape forming machine is shown, which is used for metal profiles forming. Nowadays hard turning is used for manufacturing of the rollers made of cold work tool steel, Fig. 3-b.

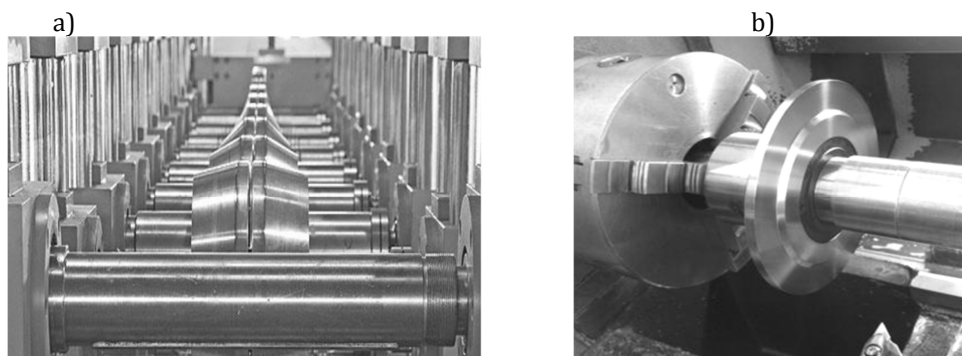


Fig. 3. Many-roller metal tape forming machine [ASMP] (a) and hard turning of hardened roller made of cold work tool steel [hardturning.pl] (b)

Each of the roller has different dimension and shape. The grinding process is definitely too expensive for machining of these parts. The manufacturer of the rollers uses a high-stiffness lathe and cutting wedges made of ceramic or CBN. Coolant is used because of the problems with keeping appropriate

dimensions during machining. The tool life of inserts is shorter, but it is easier to control dimensions and tolerance which change under the influence of heat generated in the shear zone.

### 3. Researches of hard turning

#### 3.1. Experiment equipment, work piece and tool

Turning experiments were executed in dry conditions using a universal lathe type Knuth Masterturn 400 with 7.5 kW spindle power, Fig. 4.

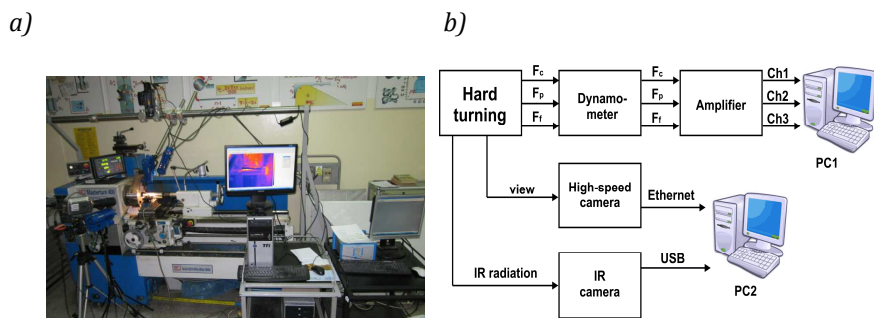


Fig. 4. The research stand (a) and scheme of equipment (b)

The work piece material was cold work tool steel (NC10) which is popularly used in cold forming and roll forming. Its chemical composition (in wt.%) is given in Table 3. The work pieces were hardened followed by tempering process to attain three different hardness levels: 56.5; 58.5 and 62 HRC, Fig. 5-a. Its hardness was measured by a hardness tester Rockwell HR150A. For each of three shafts 11 experiments (and several additional attempts) were carried out according to Hartley investigation plan:  $v_c \in (80-160)$ ,  $f \in (0.058-0.153)$  and  $a_p \in (0.1-0.5)$ . Additional high-speed camera (Phantom) and IR camera (FLIR) were used to record the of chip formation and temperature in the cutting zone. During experiment cold light system Dedocool was applied.

Table 3. Chemical composition of cold work tool steel NC10

Steel	Chemical composition [%]							
	C	Cr	Mn	Si	Ni, Cu	Mo, W	V	P, S
NC10	1.5- 1.8	11- 13	0.15- 0.45	0.15- 0.4	<0.35	<0.2	<0.15	<0.03



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The removable cutting inserts CNGA120408, manufactured by WNT company, were made of CBN tool material, commercially known as PBC25-S (65% of CBN) and PBC40-S (55% of CBN). Tool holder is codified as DCLNR 2525 M12 and it was produced by Sandvik Coromant company. Tool geometry is described as:  $\kappa_r = 95^\circ$ ,  $\lambda_s = -6^\circ$ ,  $\gamma = -6^\circ$ . The three components of the cutting forces: feed force ( $F_f$ ), passive force ( $F_p$ ) and main force ( $F_c$ ), schematically shown in Fig. 5-b were recorded using a standard quartz dynamometer (Kistler) with amplifier 5070A and DynoWare software.

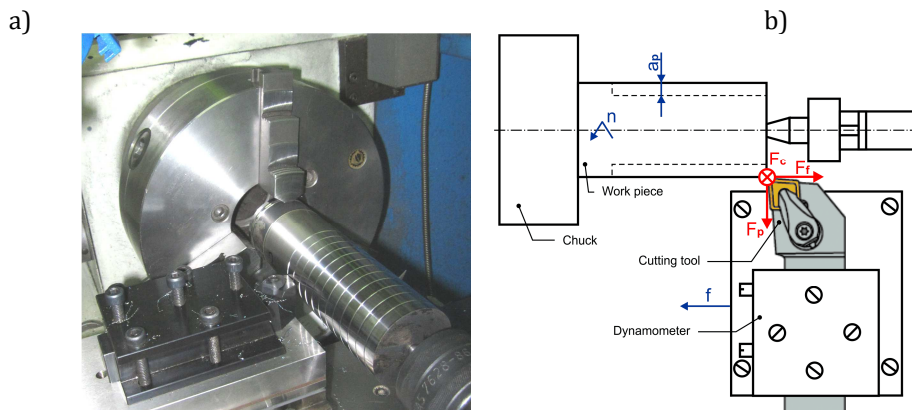


Fig. 5. Work piece material and cutting tool (a) and kinematic scheme (b)

Surface roughness was measured for each of cutting conditions and was obtained by means of Mitutoyo SurfTest SJ-201P and Intra Taylor-Hobson profilometer. The measurements were repeated three times at three reference lines equally positioned at  $120^\circ$ . The presented results of forces and surface roughness are an average of these values. Volumetric metal removal rate was calculated, acc. to equation (1), belongs to the range:  $Q \in (1.26 \div 8.05) \text{ cm}^3/\text{min}$ :

$$Q = a_p \cdot f \cdot v_c \quad (1)$$

### 3.2. Results of researches

#### 3.2.1. Surface roughness

Parameters of the surface roughness obtained after hard turning are as follow:  $Ra \in (0.25-0.89) \mu\text{m}$ ;  $Rz \in (1.44-4.1) \mu\text{m}$ ;  $Rq \in (0.3-1.02) \mu\text{m}$ . The lowest values of surface roughness have been obtained for the lowest feed rate, according to the relation:

$$Rz_t = f^2 / (8 \cdot r_\epsilon) \quad (2)$$

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The theoretical equation (2) means that the highest value of roughness should be obtained for the highest value of feed.

Hardness of work piece material affects the roughness results, Fig. 6-9. When the hardness of machined work piece material is higher obtained roughness is lower. During machining other types of steel - with other tool materials - results may be quite different.

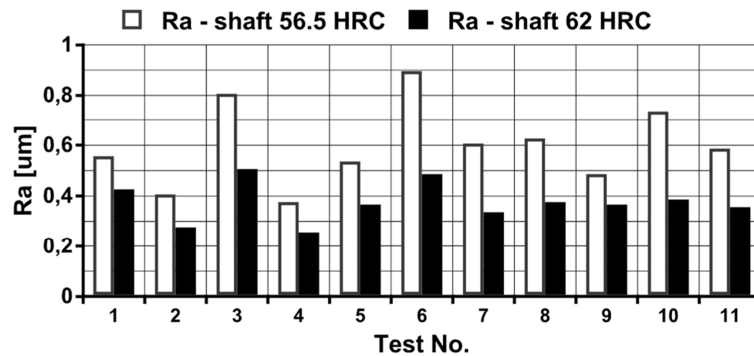


Fig. 6. Effect of hardness on the surface roughness Ra after hard turning of cold work tool steel (NC10, 56.5 and 62 HRC)

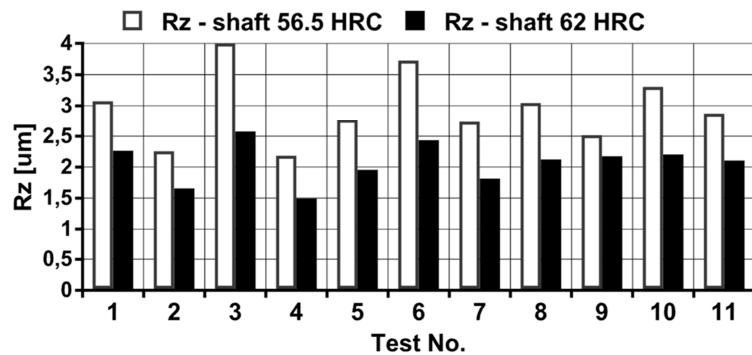


Fig. 7. Effect of hardness on the surface roughness Rz after hard turning of cold work tool steel (NC10, 56.5 and 62 HRC)

Feed rate has a dominant influence on the surface roughness. Influence of cutting speed and depth of cut is smaller, Fig. 8. When feed rate increases the surface roughness increases, too.

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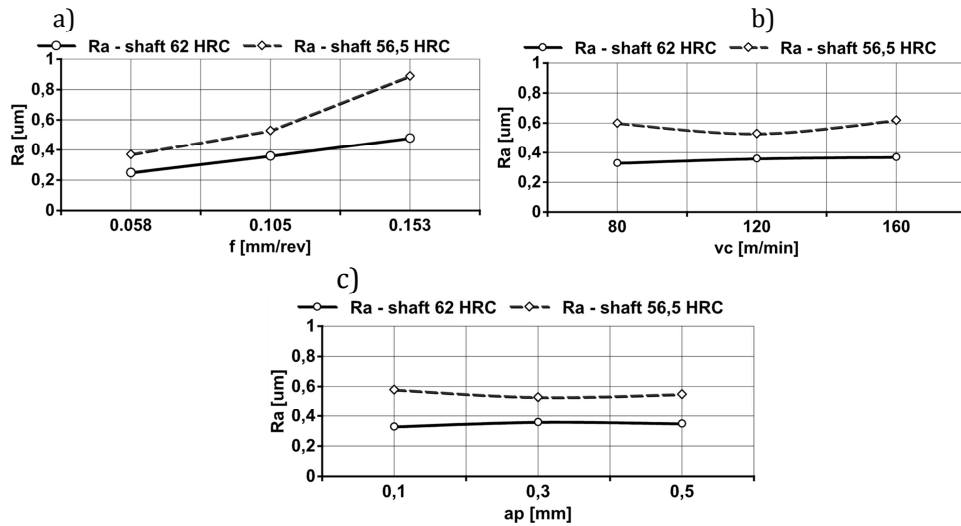


Fig. 8. Dependence between surface roughness and: a) cutting speed ( $f=0.105$  mm/rev,  $a_p=0.3$  mm), b) feed rate ( $v_c=120$  m/min,  $a_p=0.3$  mm), c) depth of cut ( $v_c=120$  m/min,  $f=0.105$  mm/rev); hardness 56.5 HRC and 62 HRC

### 3.2.2. Cutting forces

It is difference between hard turning and classic turning, considering cutting force components values. Usually values of the conventional cutting force components increase gradually in the following order [16] [17]:

$$F_c > F_p > F_f \quad (3)$$

whereas for hard turning, the highest component is  $F_p$ , which means:

$$F_p > F_c > F_f \quad (4)$$

The results presented in Fig. 9-13 are consistent with their relationship (4). Measured values of the cutting force components were in the range:  $F_c \in (60-240)$  N,  $F_p \in (110-285)$  N,  $F_f \in (25-160)$  N.

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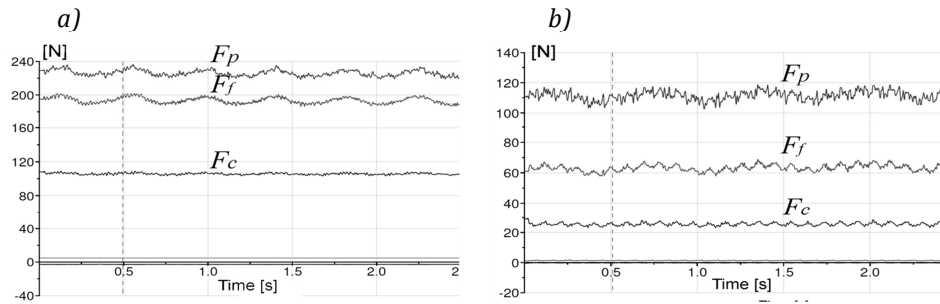


Fig. 9. Example of measured components of the total cutting force for hardened shaft made of cold work tool steel (NC10, 56.5 HRC);  $v_c=120$  m/min, a)  $f=0.153$  mm/rev,  $a_p=0.3$  mm; b)  $f=0.105$  mm/rev,  $a_p=0.1$  mm

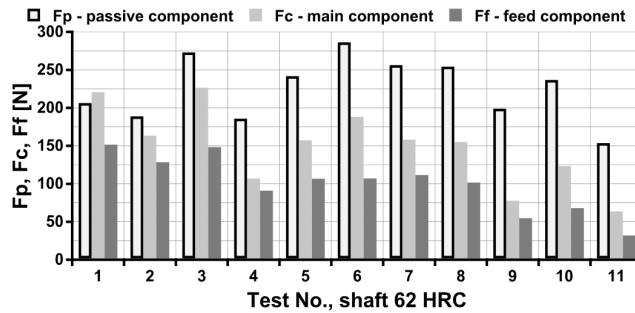


Fig. 10. Comparison between components of the total cutting force in turning of hardened cold work tool steel (NC10, 62 HRC) with the CBN tool (PBC-40S)

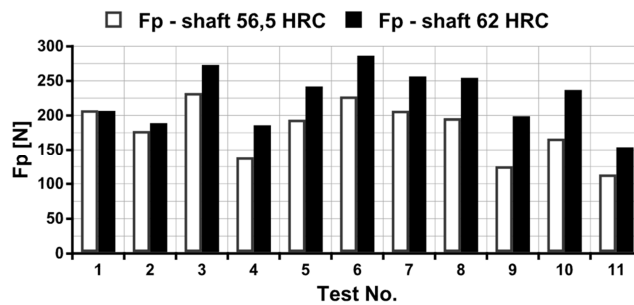


Fig. 11. Effect of hardness of work piece material on passive force component  $F_p$  during turning cold work tool steel (NC10, 56.5 and 62 HRC)

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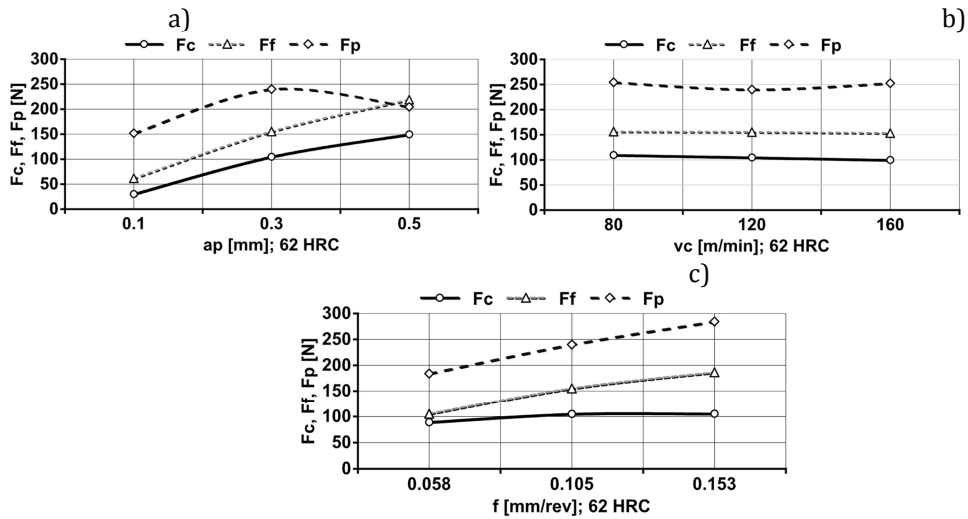


Fig. 12. Effect of: a) depth of cut ( $f=0.105$  mm/rev,  $v_c=120$  m/min), b) cutting speed ( $a_p=0.3$  mm,  $f=0.105$  mm/rev), c) feed rate ( $a_p=0.3$  mm,  $v_c=120$  m/min) on total force components during turning of cold work tool steel (NC10, 62 HRC)

### 3.2.3. Chip formation and heat flow

Phantom high-speed camera has recorded movies of chip formation with 2400 frames/second, Fig. 13-17. During experiment the influence of cutting conditions on the chip formation has been observed. Color of chip surface was changed under the influence of heat.

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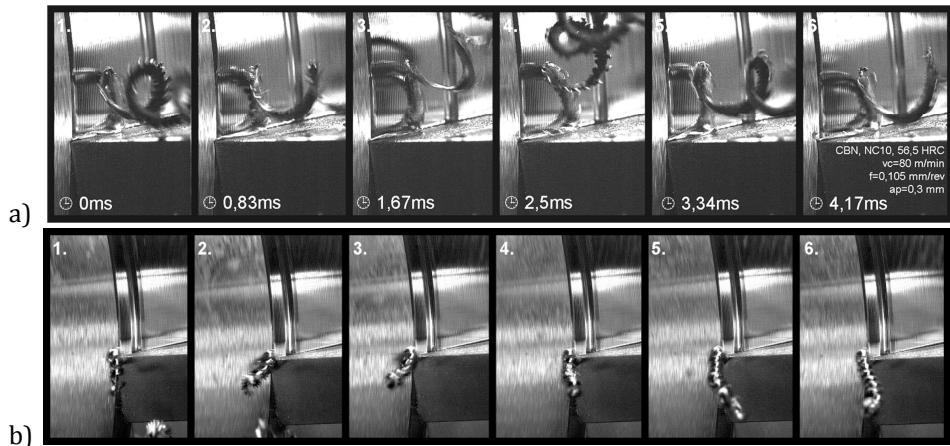


Fig. 13. The sequence of chip formation during hard turning of cold work tool steel (NC10) with CBN tool: a) 56.5 HRC,  $v_c=80$  m/min,  $f=0.105$  mm/rev,  $a_p=0.3$  mm, b) 62 HRC,  $v_c=96.9$  m/min,  $f=0.134$  mm/rev,  $a_p=0.18$  mm



Fig. 14. Influence of feed rate on chip formation (NC10; 62 HRC;  $a_p=0.3$  mm,  $v_c=120$  m/min): a)  $f=0.058$  mm/rev, b)  $f=0.105$  mm/rev, c)  $f=0.153$  mm/rev

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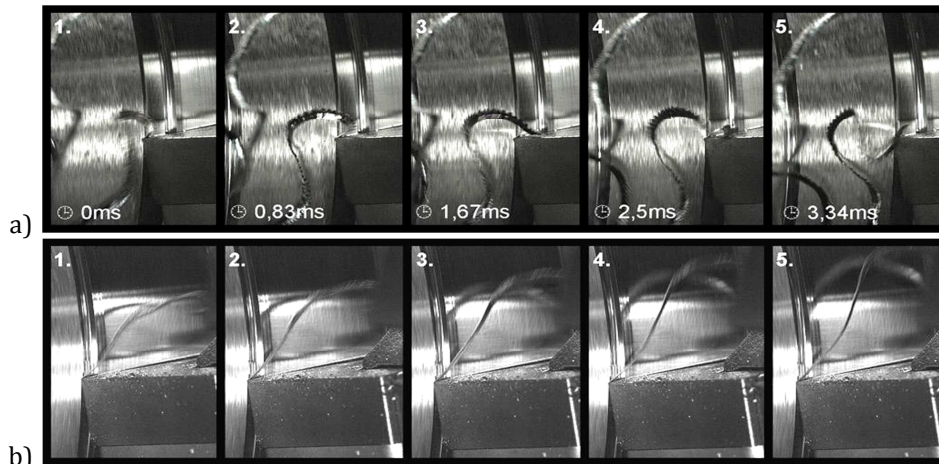


Fig. 15. Influence of cutting speed on chip formation (NC10; 62 HRC;  $a_p=0.3$  mm,  $f=0.105$  mm/rev): a)  $v_c=80$  m/min, b)  $v_c=160$  m/min

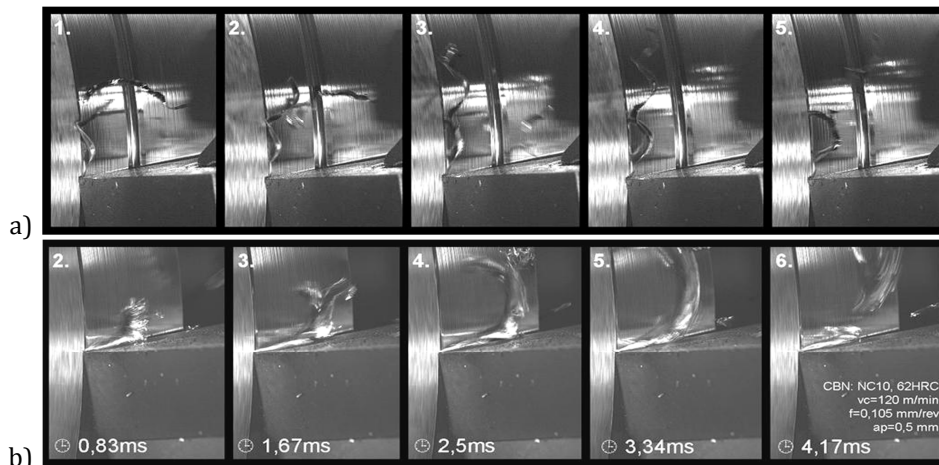


Fig. 16. Influence of depth of cut on chip formation (NC10; 62 HRC;  $f=0.105$  mm/rev,  $v_c=120$  m/min): a)  $a_p=0.1$  mm, b)  $a_p=0.5$  mm

IR camera has recorded temperature changes in the cutting zone with 24 frames/second, Fig. 17. Almost all of generated heat is eliminated while getting rid of chips. It has been observed that if the cross-section area is smaller temperature of chip is higher. When the depth of cut or feed rate is higher, the cross-section is also higher and temperature of chip is lower. When cutting speed increases, temperature of chip and wedge also increases.

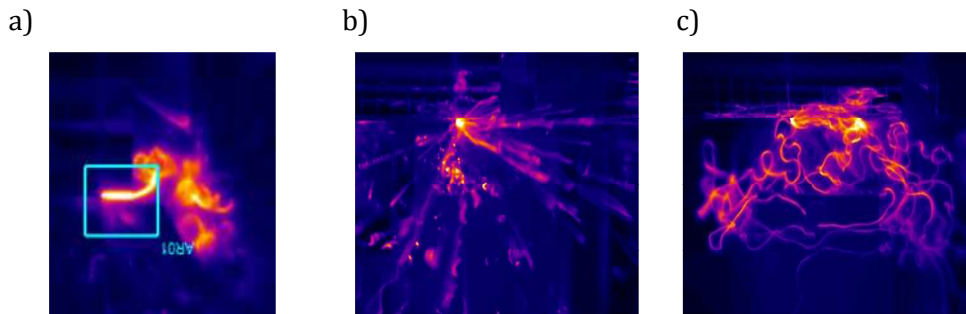


Fig. 17. Thermograms of cutting hardened cold work tool steel (NC10, 62 HRC) with the CBN tool: a)  $v_c=120$  m/min,  $f=0.105$  mm/rev,  $a_p=0.5$  mm, b)  $v_c=143$  m/min,  $f=0.134$  mm/rev,  $a_p=0.42$  mm c)  $v_c=160$  m/min,  $f=0.105$  mm/rev,  $a_p=0.3$  mm

#### 4. Conclusion

Turning of hardened cold work tool steel with CBN insert has a lot of advantages in comparison with grinding such as shorter production process, higher metal removal rate, easy cutting of complex contours and high flexibility. Hard turning is a quite good solution for semi-finishing and finishing machining of metal parts when the hardness is in the range 55-62 HRC. Cutting parameters and hardness of machined material influence on the surface parameters and tool: feed rate and hardness on surface roughness; hardness, depth of cut and feed rate on the values of total force components; cutting speed on the temperature in the cutting zone and tool wear. Dry cutting generates higher temperature on the tool wedge and the tool length increases. In result the cylindricity deviation is higher. In this case coolant should be taken into consideration but it may bring about some thermal shock on the cutting tool. Although hard machining has a lot of advantages, it won't be able to exclude completely the grinding process of hardened metal parts.

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## References

- [1] KLOCKE F., BRINKSMEIER E., WEINERT K. (2005) *Capability profile of hard cutting and grinding processes*. Annals of the CIRP. 2.54:557-580.
- [2] TÖNSHOFF H. K., ARENDT C., BEN AMOR R. (2000) *Cutting of hardened steel*. Annals of the CIRP 2.49:547-566
- [3] KUNDRÁK J., MAMALIS A.G., MARKOPOULOS A. (2004) *Finishing of hardened boreholes: Grinding Or hard cutting?* Materials and Manufacturing Processes 6.19:979-993.
- [4] AOUICI H., YALLESE M.A., CHAOUI K., MABROUKI T., RIGAL J.-R. (2012) *Analysis of surface roughness and cutting force components in hard turning with CBN tool*. Measurement. 3.45:344-353.
- [5] BYRNE G., DORNFELD D., DENKENA B. (2003) *Advancing cutting technology*. Annals of the CIRP. 2.52:483-507.
- [6] COELHO R.T., NG E.G., ELBESTAWI M.A. (2007) *Tool wear when turning hardened AISI 4340 with coated PCBN tools using finishing cutting conditions*. Int. Journ. Machine Tools & Manufacture. 2.47:263-272.
- [7] DOBRZYŃSKI M., ORŁOWSKI K. (2009) *Toczenie wykończeniowe powierzchni otworów w stanie utwardzonym*. Obróbka skrawaniem 3. Zaawansowana technika pod red. H. Latosia. Bydgoszcz. 41-48.
- [8] BARTARYA G., CHOUDHURY S.K. (2012) *State of the art in hard turning*. International Journal of Machine Tools and Manufacture. 1.53:1-14.
- [9] SCHUMANN W. (2007) *Bearbeiten harter Eisenwerkstoffe mit geometrisch bestimmter Schneide*. IDR. 3.41:52-71.
- [10] DAVIM J.P. (2011) *Machining of hard materials*. Springer. London.
- [11] KAWALEC M. (2006) *Efekty technologiczne obróbki na twardo materiałów metalowych*. Mechanik. 1.79: 20-26.
- [12] SIWIEC J. (2011) *Obróbka materiałów w stanie utwardzonym*. Czasopismo techniczne. Mechanika. 15.108:93-100.
- [13] KAWALEC M. (2009) *Skrawanie ostrzami zdefiniowanymi geometrycznie zahartowanych stali. Rozwój, efekty i tendencje*. Obróbka skrawaniem 3, Zaawansowana technika, pod red. H. Latosia. Bydgoszcz. 9-30.
- [14] GRZESIK W. (2011) *Polepszenie jakości technologicznej i użytkowej części z materiałów utwardzonych. Cz. II Integracja skrawania na twardo i wykończeniowej obróbki ścierniej*. Mechanik. 8:9.84:650-656.
- [15] [www.hardtturning.pl](http://www.hardtturning.pl)
- [16] MAŇKOVÁ I. (2002) *Monitoring of cutting forces and tool wear when hard turning*. Journal of Production Processes and Systems. 1:75-80.
- [17] KUNDRÁK J., BANA V. (2004) *Model for cutting forces in hard turning of bores*. Annals of DAAAM. :241-242