Journal of Machine Engineering, Vol. 12, No. 1, 2012

hard turning, CBN tool
burnishing, superfinishing
surface roughness

Miroslav NESLUSAN[1], Wit GRZESIK[2]
Krzysztof ZAK[2]

ANALYSIS OF SURFACE ROUGHNESS ON BEARING STEEL PARTS AFTER CUTTING, SUPERFINISHING AND BURNISHING OPERATIONS

The different technological operation can form the variety of surface with the different functionality. In this paper the surface texture produced by hard turning of a quenched 100Cr6 steel of 62-64 HRC hardness using mixed ceramic (MC) tools and subsequent superfinishing and multipass burnishing operations is characterized by means of a number of roughness parameters. Both conventional and wiper MC cutting tool inserts were employed. The main objective of this study is to improve service properties of the turned surfaces of bearing parts by additional removal and non-removal treatments in order to obtain smoother surfaces with lower surface roughness and better bearing characteristics.

1. INTRODUCTION

Machine parts consisting of hardened steel are high performance components which are often loaded near their physical limits. The functional behaviour of machined parts is decisively influenced by the fine finishing process which represents the last step in the process chain and can as well be undertaken by cutting as grinding or turning. For this reason, fine finishing is defined as an important process and its results have to satisfy high quality requirements. The product specific issues and demands also meet effectiveness, time to market and process agility.

Development in machine tools as well as in process technology focus on cutting hardened steel and rapidly lead to a high raised industrial relevance of hard cutting. In fact, hard cutting can seriously be regarded as an alternative for grinding operations under certain circumstances. High flexibility and the ability to manufacture complex workpiece geometry in one-set represent the main advantages of hard cutting in comparison to grinding [1]. Furthermore, the substitution of grinding process with cutting processes enables to avoid coolants and therefore can actually be regarded as interesting alternative even from the ecological point of view [1],[2].

Machining of hardened materials (steels and cast irons) using mixed ceramic or CBN

[1] Affiliation of the first author Faculty of Mechanical Engineering, University of Žilina, Univerzitná 8215/1, Žilina 010 26, Slovak Republic
[2] Faculty of Mechanical Engineering, Opole University of Technology, 5 Mikołajczyka Street, Opole 45-271 Poland

tools is quite a popular removal method of producing parts in such branches as automotive, bearing, hydraulic and die and mold making sectors [3]. Finishing operation such as hard turning (or grinding) and the following superfinishing are implemented into the technology after heat treatment. Heat treatment process changes mechanical properties of parts and also their dimensions and shape. Hard turning or grinding operations in bearing industry enable to remove unfavourable deformations of parts after heat treatment and reach the required precision of parts. Moreover, these operations form the final state of surfaces from the point of view of microgeometry and also the initial stage of microgeometry for the most loaded surfaces such as bearing orbits. Except application of conventional tool geometry (considering hard turning), the wiper geometry can be successfully applied for hard turning operations [4]. The application of the so called combined (hybrid) machining was also investigated [5]. The low values of surface roughness can be kept under the high feeds. This way the cutting time and also the associated production costs can be reduced. Superfinishing operations are carried out on ring orbits and affects only surface roughness while ring shapes and dimensions stay nearly untouched. Burnishing operations represent an option in surface processing affecting not only the surface roughness but also with a strong impact on such aspects as surface hardening, redistribution of stress state and structure modification. The different operations form the different state of surface integrity and the specific aspects should be taken into the consideration in connection with their application in the practice. In this paper, a very detailed analysis of machined surfaces of hardened 100Cr6 steel parts generated by sequential processes including hard turning and optionally superfinishing or burnishing operations was performed. This is due to the fact that conventional hard machining does not produce, in many cases, surfaces with demanding service/exploitation properties (fatigue life, bearing properties, rolling/sliding contact loads, etc.) [6].

2. EXPERIMENT CONDITIONS

Tab. 1. Specifications of machining conditions

Symbol of operation	Machining operation	Process conditions
HT-S1 HT-S2	Hard turning with mixed ceramic tool. Conventional cutting insert- SNGN 120408 T01020. Tool geometry: r_ε=0.8mm, $b_{□}$=0.1mm, $□_{n'}$=-20	HT-S1, HT-W1 v_c=150 m/min, f=0.064 mm/rev, a_p=0,15 mm HT-S2, HT-W2 v_c=150 m/min, f=0.21 mm/rev, a_p=0.15 mm
HT-W1 HT-W2	Hard turning with mixed ceramic WIPER tool. Cutting insert-CNGA 120408 T01020 WG. Tool geometry: r_ε=wiper, $b_{□}$=0.1mm, $□_{n'}$=-20	
HT-S1,S2+SF HT-W1,W2+SF	Superfinishing after hard turning. Honing stone reference- 99A320N10 V	v_c=26 m/min, f=0.1 mm/rev, t≈45min. Oscillation frequency-680 osc/min, applied force-40 N, amplitude-3.5 mm, grain size-29 □m, cooling medium: 85% kerosene and 15% machine oil
HT-S1,S2+BUR HT-W1,W2+BUR	Ball burnishing with 3-4 passes after hard turning	Ball of 12 mm diameter, applied force-40 N, cooling medium: 85% kerosene and 15% oil

Machining trials were performed on the specimens made of 100Cr6 (AISI 52100) steel with Rockwell's hardness of 60-64 HRC. Mixed ceramic cutting inserts containing 71%Al2O3, 28% TiC and 1% of additives were used. Process conditions for all operations performed and characteristics of the tools used are specified in Table 1. All experiments were carried out using the following machine and devices: 3-axis CNC lathe, special superfinishing device and a ball burnishing head, 3D profilometer, model TOPO-01P with a diamond stylus radius of 2 μm.

3. EXPERIMENTAL RESULTS

3.1. SURFACE PROFILES AND HEIGHT PARAMETERS

All ISO surface roughness parameters measured were clustered into 4 groups, i.e. height, amplitude distribution, mixed and bearing area parameters [7]. They are successively presented in Figs. 3-6 taking into account surface modifications resulting from abrasive and burnishing operations. All parameters are derived from the surface profiles illustrated in Figs. 1 and 2.

Hard turning and sequential turning-abrasive and turning–burnishing technological processes produce a variety of surfaces with different geometrical and service properties. The surface profiles and also the height parameters illustrated that the Wiper tool enables to obtain the significantly lower values of the height parameters than standard HT tool geometry.

Fig. 1 depicts that surfaces produced by conventional ceramic tool contains significantly higher peaks and deeper valleys than that produced by Wiper tool. If the feed rate increases to f = 0,21 mm/rev machining with the standard insert allow generating surface with the regular distribution of tool nose traces, as shown in Fig. 1b. Profiles produced under the low feed (Fig. 1a) and Wiper insert (Fig. 1d) can be evaluated as a semi periodic with the irregularities occurred in the profiles. Character of these irregularities for standard tool geometry differs from irregularities in profiles produced by Wiper tool.

Surfaces produced by superfinishing (Figs. 1e) are similar to ground surfaces with numerous small peaks and valleys formed by grains in the tool surface – contact. Burnishing results in visible smoothing by plastic deformation with irregularities in the profile. The height parameters correspond with profiles. They are illustrated Figs. 3 and 4. Except tool geometry, the significant role takes applied feed. It should be noticed that relation considering tool geometry and feed influence stays nearly constant. The measured values of Ra after turning with 0,064 mm/rev feed reach only 30% of values after turning with 0,21 mm/rev for standard and also Wiper tool. Moreover, the measured values of Ra for Wiper tool are 20% of values for HT tool (for feed 0,21 mm/rev) and 22 % for 0,064mm/rev feed.

It is evident that burnishing operation strongly affects the measured values after turning with standard tool. The differences between Ra values are rather small for Wiper tool (0,01 μm for 0,064 mm/rev feed and 0,18 μm for 0,21mm/rev feed). On the other hand, this difference for standard tool is 0,51 μm for 0,064 mm/rev feed and 2,15 μm for 0,21

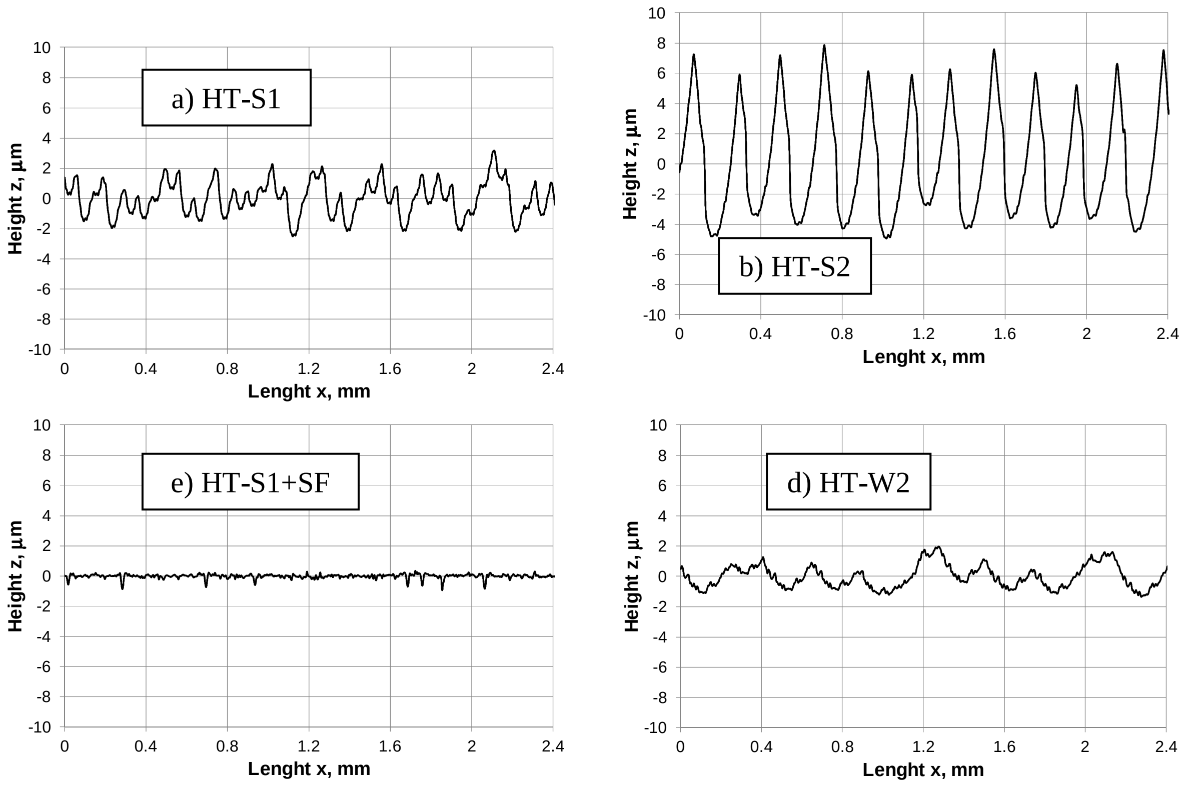

Fig. 1. Surface profiles for 100Cr6 steel – without burnishing

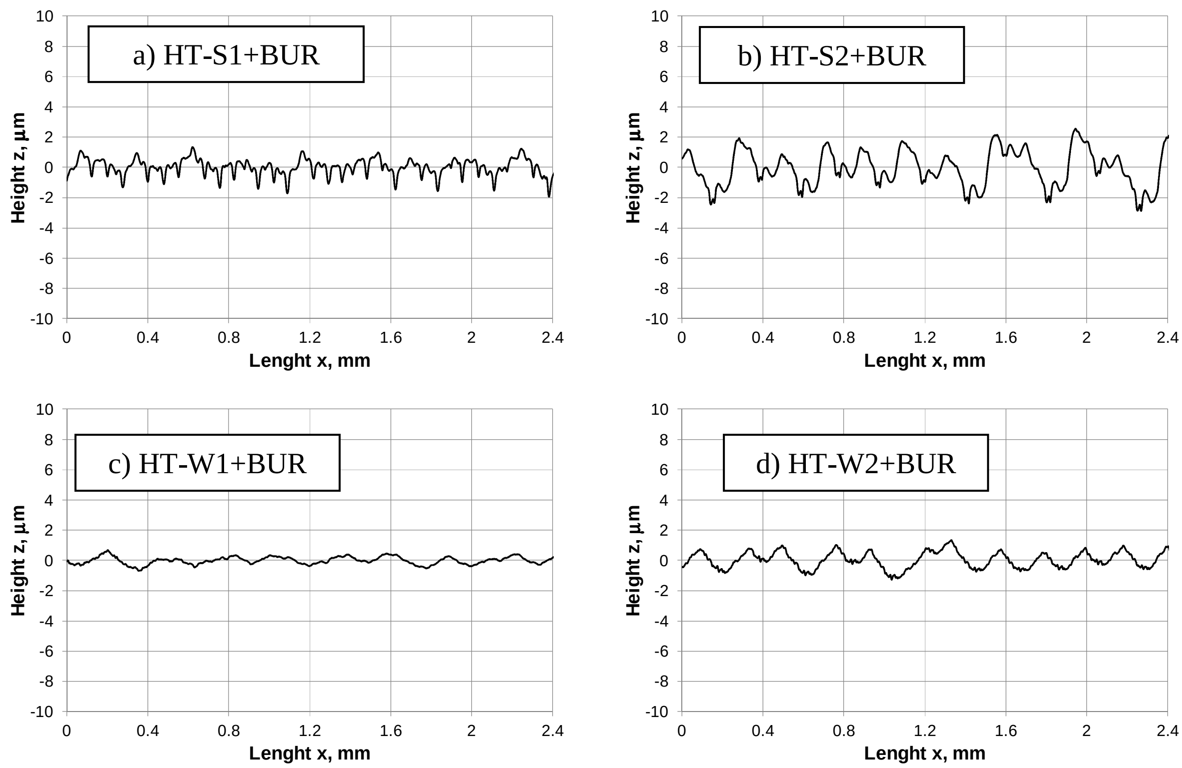

Fig. 2. Surface profiles for 100Cr6 steel – with burnishing

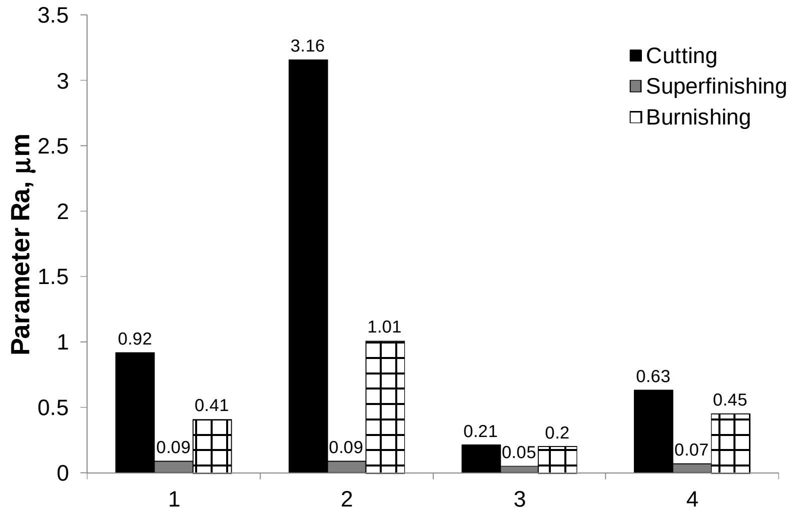

Fig. 3. Changes in the parameter Ra for: HT-S1, HT-S1+SF and HT-S1+BUR (1), HT-S2, HT-S2+SF and HT-S2+BUR (2), HT-W1, HT-W1+SF and HT-W1+BUR (3), HT-W2, HT-W2+SF and HT-W2+BUR (4)

mm/rev feed. Moreover, in the case of HT-W1+BUR Rz value is higher than that before burnishing operation as illustrates Fig. 4. Fig. 4 also illustrates transformation in valleys and peaks ratio (peaks are reduced and valley become more dominant). Fig. 4 illustrates the values of Rz and also associated Rp (maximum peak height on the profile) and Rv (maximum valley depth on the profile) values. It is evident that the ratio between peaks and valley depends on the machining process variant, as documented previously in [8].

It should be noted that the smoothing effects depends on the state of surface finish produced in hard turning operations using standard or wiper inserts. Additional SF produced surfaces with Ra parameter of 0.05-0.09 µm, whereas burnishing reduces Ra parameters to 0.20-1.0 µm (minimum value of 0.20 µm for HT-W1+BUR variant).

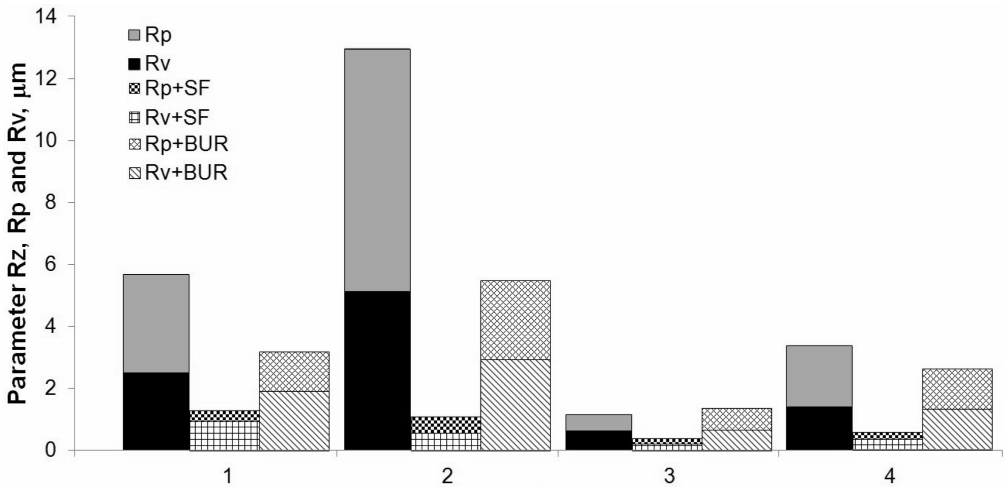

Fig. 4. Fractions of maximum peaks and depths in the profile height: HT-S1, HT-S1+SF and HT-S1+BUR (1), HT-S2, HT-S2+SF and HT-S2+BUR (2), HT-W1, HT-W1+SF and HT-W1+BUR (3), HT-W2, HT-W2+SF, HT-W2+BUR (4)

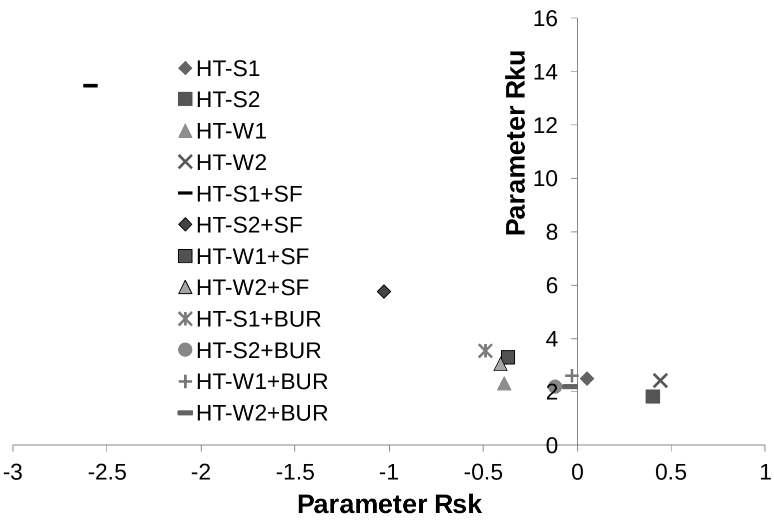

Fig. 5. Map of normalized kurtosis (Rku) versus skewness (Rsk) for hard turning (HT-S, HT-W) and finishing (SF, BUR) operations

3.2. AMPLITUDE DISTRIBUTION PARAMETERS

Fig. 5 shows the plot kutoris Rku versus skewness Rsk whose values can be positive, zero or negative. In general, different HM processes produce different Rsk/Rku envelopes, i.e. surfaces with good bearing (negative values of Rsk) or locking (positive values of Rsk) properties. Maximum negative values of Rsk=-2.59 and -1 were recorded for HT-S1+SF and HT-S2+SF sequential processes respectively. While negative values of Rsk can be usually obtained after superfinishing operations (HT-S1+SF or HT-S2+SF), the positive values are often produced under the high feeds as shows Fig. 5. Rsk values for burnishing operations are close to zero as illustrates Fig. 5 (except HT-S1+BUR). In general, higher negative values of Rsk correspond to values of kurtosis Rku higher than 3. The lowest values of Rku was measured after burnishing and application feed 0,21 mm/rev for standard and also Wiper inserts.

3.3 BEARING AREA PARAMETERS

Fig. 6 compares bearing curves obtained for specified machining operations included into this study. Fig. 6 shows that increase in feed for standard insert results in significant differences in the bearing curves but the characteristic S-shape (degressive – progressive) does not change (curves A and B in Fig. 6). Wiper geometry is less sensitive to the feed variation and bearing curves for different feeds are nearly the same. S-shape of bearing curves can be also obtained (curves C and D in Fig. 6). Except HT-S1+BUR variant, the next three bearing curves obtained after burnishing are nearly the same. On the other hand, while bearing curve for HT-S1+BUR variant has a typical S-shape, the next three bearing curves (after burnishing) are particularly modified and become more degressive.

In particular, superfinishing and burnishing operations can improve bearing properties of surfaces on hardened parts produced by HT. The lowest values of reduced peak height (derived from bearing curves) were obtained after superfinishing operations. The lowest value of Rpk parameter was obtained for HT-W1+SF variant (0,05 μm) and the highest for HT-S1+SF variant (0,1 μm). Rpk values after ball-burnishing operations are higher. The lowest value of Rpk parameter after ball-burnishing operations was obtained for HT-W1+BUR variant (0,15 μm) and the highest for HT-S2+BUR variant (0,54 μm).

Concerning the material ratio at 20% depth (Rmr(20)), it is localized at c in a close range of 67-74% except variants obtained after A and B (application of standard tool geometry and the following superfinishing operations), as shows Fig. 6. As illustrates Fig. 6, bearing curves and also Rmr(20) values obtained with standard tool geometry and superfinishing operations are very sensitive to applied feed. While Rmr(20) value for HT-S1+SF variant is 79%, in the case of HT-S2+SF variant Rmr(20) value is only 59%. Additional ball-burnishing operations eliminate this sensitivity. However, the significant differences in Rmr values can be derived in the deeper levels of the bearing curves.

4. SUMMARY

Hard turning and also integrated superfinishing or ball-burnishing technological processes enable to obtain a variety of surface with the different microgeometry and so associated functionality. All operations investigated in this paper can be executed at variety of conditions. This study compares three different strategies (cutting, superfinishing and burnishing) under the limited range of applied conditions.

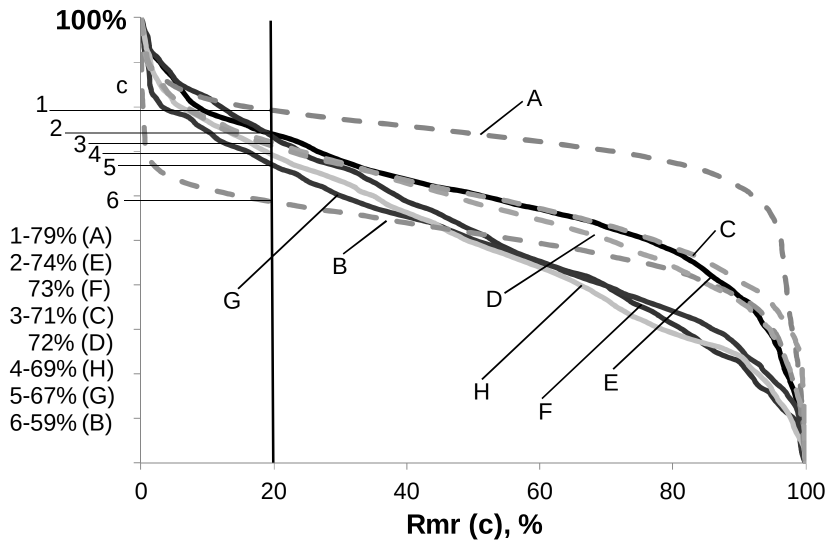

Fig. 6. Bearing curves for 100Cr6 steel after: HT-S1+SF (A), HT-S2+SF (B), HT-W1+SF (C), HT-W2+SF (D), HT-S1+BUR (E), HT-S2+BUR (F); HT-W1+BUR (G); HT-W2+BUR (H)

On the other hand, results of experimental measurements show that Wiper geometry enables to obtain surfaces with low values such as Ra or Rz at high feeds. Wiper inserts represent the tool with a high potential considering production time and costs savings. However, the most suitable values of Rsk (negative with better bearing properties) were obtained with standard tool geometry and additional superfinishing.

Burnishing and first of all superfinishing operations can improve bearing properties of surfaces on hardened parts. It is possible to obtain surface with minimum running-in period (minimum Rpk values of 0,05 μm).

Microgeometry of surface represents only a particular task in investigation of surface integrity research. Functionality of parts usually depends on properties of surfaces in contact. Surface state can be expressed in many terms such as residual stresses, modifications of surface hardness, structure transformation, surface oxidation, etc. Practice application of new tools, operations and strategies is always connected with surface integrity in complexity of all parameters and their mutual relations.

REFERENCES

[1] TONSHOFF H. K., ARENDT C., AMOR R. B., 2000, *Cutting of Hardened Steel*, CIRP Annals 49/2/547 – 564.

[2] HEO S. J., 2008, *Environmentally conscious hard turning of cemented carbide materials on the basis of micro-cutting in SEM: stressing four kinds of cemented carbides with PCD tools*, J. of Mech. Science and Technology, 22/1383-1390.

[3] GRZESIK W., RECH J., ŻAK K., 2007, *Surface finish on hardened bearing parts produced by superhard and abrasive tools*. International Journal Machine Tool and Manufacturing, 255-262.

[4] GRZESIK W., WANAT, T., 2005, *Comparative Assesment of Surface Roughness Produced by Hard Machining with Mixed Ceramic Tols including 2D and 3D Analysis*, J. of Mat. Processing Technology, 169/364 – 371.

[5] KUNDRÁK J., 2010, *Choosing Procedures for Finishing Precision Manufacturing*, In-tech, Prague, 465 - 468.

[6] KLOCKE F., BRINKSMEIER E., WEINERT K., 2005, *Capability profile of hard cutting and grinding processes*. CIRP Annals, 54/557-580.

[7] GRIFFITHS B., 2001, *Manufacturing Surface Technology*, Penton Press, London (England)

[8] GRZESIK W., ZAK K., BROL S., 2009, *Surface finishing in turning of nodular cast iron using coated carbide and silicon nitride ceramic tools*, Manufacturing technology, 9/31-39.