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SURFACE QUALITY OF HARD TURNED BORE HOLES

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Abstract: Hard turning is used more and more frequently for finishing of precision hardened bores, namely for replacement of grinding. This paper studies the experimental results performed for qualifying of surfaces machined with hard boring. It presents the results of surface roughness measurements (2D, 3D) and indicates the changes occurring in the surface layer. It proves that the presented surface quality characteristics of the investigated parts suit the requirements moreover in some cases they are even better than characteristics of surfaces machined by grinding. As a summary it is stated if the cutting parameters are chosen well, surfaces and/or parts with better wear resistance and higher durability can be manufactured.

Keywords: hardened bore holes, surface measurement, roughness.

1. INTRODUCTION

The examination of the ability of hardened steels to be cut has been an outstanding research tendency.

Before hardened surfaces were machined by abrasive tools, firstly by grinding. Grinding is a process that has been used for a long time, well elaborated and established both theoretically and technically, wide-spread and an often applied process.

With the emerge of boron-nitride based tools it became possible to machine hardened steels with other cutting processes (tools with definite edges) besides abrasive procedures.

In the beginning, the theoretical and technical possibilities of cutting with tools having one definite edge were researched.

That time the requirements for parts were to achieve by cutting under conditions thought to be extreme in most of the cases (small cross section of the chip, high cutting speed, special materials, newish wear relations and so on).

As a results of development the technologies, cutting tools and machine-tools have been at our disposal with which these conditions in precision machining became usual.

Improvements in the availability (construction, price etc.) of cubic boron nitride (CBN) and CBN composite tools have made this machining (hard cutting) a process of significant industrial importance.

The quick development of the machining procedures were encouraged not only by the possibilities of the complicated combination of surfaces, but by the ever increasing number and/or the hardness of hard surfaces, because their life –time (durability) can be increased by this way, too, and thus the reliability of the products.

But is also noticeable that surfaces are increasingly more often hardened to simplify the technological process of heat treatment (e.g. in gear production where all the surfaces of the gear wheel body is hardened).

During finishing of hardened surfaces, significant mechanical and thermal effects occur, which determine largely the state of the generated surface layer. Thus, surface layer properties of the parts exposed to high load decisively determine the functional behaviour, wear resistance and fatigue life of the parts.

Because hard turning is a finishing process, its precise and detailed knowledge is very important.

2. PROBLEM STATEMENT

2.1. *Surface Roughness*

The fulfilment of requirements concerning for the surface quality is determinant in finishing because it is one criteria of the “producibility”. The geometrical quality is one part of the surface quality. In finishing of the surfaces the effort was for a long time that the smoother surface can be machined. However, building-up and function of the parts raise further question concerning for the geometry of the surface. Earlier, the giving of the average surface roughness was the general in the technical drawing, nowadays the value of the ten-point-height of the profile (Rz) is already prescribed and in addition to this the giving of the bearing length ratio (tp) is more and more frequent in precision machining [1].

The generally applicable roughness characteristics can be classified into two groups:

- the roughness characteristics connected with the height of irregularities (Ra, Rt, Rz, Rp, Rv, Rq)

- the roughness characteristics connected with the form of irregularities (Δq, Δa, λq, λa, Sk, η, tp)

The experiments proved [2] that the amplitude parameters, mainly Rt, are suitable for monitoring the wear of cylindrical bores. However, other researchers came to the conclusion in machining of bores [3] that the prediction of Rq parameter is suitable for observing the finishing and the functional wear.

The magnitude of the bearing length ratio (the value of tp), the skewness of the profile (its measuring number is Rsk) and the distribution of profile departure density are being investigated more and more frequently.

As a summarization it seems that the effort is stronger and stronger to prescribe the permitted value of the roughness characteristics for the functional surfaces of the parts justified by the real load.

In the nineties those elementary studies and research results [4, 5, 6] were published which made possible to characterize the surface microgeometry in three dimensions. The extension of the two-dimensional roughness characteristics for three-dimensional makes possible to explore and evaluate the microgeometrical conditions more truly furthermore it is also suitable for revealing and characterising numerically such properties which cannot be determined from the profile section.

The characteristics of the three-dimensional topography – on the basis of their geometrical information content – can be classified according to the following [4, 5, 7]:

- the amplitude (or height distribution) parameters (Sa, Sq, Sz, Ssk, Sku)
- the spatial parameters (Sds, Str, Std, Sal)
- hybrid (or complex geometrical) parameters (SΔq, Ssc, Sdr)
- functional parameters (or the parameters describing the functional properties) (Sbi, Sc, Svi)

The above mentioned, short and not complete review also indicates that it is worth enlarging the area of the investigated roughness characteristics to define the microgeometry of the surface more precisely. It is mainly justified for finishing machining because the formed surface has a significant effect on the functional behaviour of the part and in consequence on the life time of that, too.

2.2. Microhardness

The microhardness investigations in the case of hard turned parts indicate different results [8]. Some say that the microhardness hardly changes while according to others it significantly increases or decreases in the machined surface especially as a function of the flank wear. The investigations of several researchers proved [8, 9, 10] that hardened up layer develops during hard turning. Compared to the hardened layer before machining the scale of the hardening up is about 20-30 % and its maximum value varies between 850 and 1400 HV depending on the machined material. If the effect of flank wear is taken into account it was observed that in cutting of hardened steel with high hardness the rate of the hardening up is higher when using sharp tool and its maximum value appears in deeper layers measured from the surface level [9].

2.3. Residual Stress

The residual stress is defined as a stress, which occurs in the elastic body apart from the external loads. Residual stresses during machining are generated by mechanical and thermal loads and phase transformations [8]. The mechanical load generated by cutting forces creates inhomogeneous and plastically deformed layers under the machined surface. In cutting with high speed, the yield stress of the workpiece reduces, resulting in significant changes in the residual stress [10]. Measurement of the residual stress is mainly done by X-ray diffraction. This technique determines the alteration of distances between the atomic lattice planes.

The residual stress generated in the machined surface is influenced by the material, the preparation of the tool applied in finishing, the technological data, and the properties of the workpiece to be machined. The hardness of the steel is a significant determining factor, as with the increase of the hardness, the compressive residual stresses increases, and its maximum shifts towards the deeper area of the surface layer [11, 12].

Hard turning may result in the generation of tensile residual stresses, which within a few microns beneath the surface, transforms into compressive residual stresses [13].

Edge preparation, (e.g., chamfer or edge honing), and the rake angle of the cutting tool influences the residual stresses developing in cutting [12]. Tool wear modifies the magnitude of the residual stresses, and its maximum value shifts to deeper layers measured from the machined surface level [8, 14].

2.4. White Layers

Due to the high temperature and frictional heat developed during cutting, phase transformations take place in the microstructure of the material. The structure of the machined surface may significantly deviate from the original state [13, 15, 16].

When examining the microstructure of hard turned parts it was proved [15] that the conditions of appearance of the white layer can exist, it can appear as well as in the case of grinding. The white layer is a result of the microstructural change – it mainly consists of austenite – whose name issues from that it withstands the traditional etchants and because of the fine-grained microstructure the grain texture cannot be seen when investigating it under scanning electron microscope thus it appears as white-coloured. The white layer has high hardness which is sometimes higher than that of the bulk.

In cutting of hardened steels with high hardness, the origin and/or thickness of rehardened layers are influenced by the state of the tool, the tool geometry and the technological data from which the flank wear and the cutting speed are mainly determinant [15].

3. EXPERIMENTAL CONDITIONS

The investigation of surface quality was performed on bores with diameter 50 mm, which was machined by hard turning. Among the roughness characteristics 2D and 3D rou7ghness parameters were studied. The changes occurring in the surface layer during hard turning was also investigated. In this case the microhardness, the residual stress and the possible appearance of white layer were examined.

3.1. Applied machines and tools

Table 1 shows the technical data of machines and tools that were used in this study.

Table 1. Technical data of Machines and Tools

	Hard turning					
Machine tool	PITTLER PVSL-2 hard turning lathe					
Clamping	3 jaws chuck					
Cutting tool /	CNMA 120408 (CBN 7020)					
	α	γ	λ	κ_r	ε	r_ε
	6°	-26°	-6°	95°	55°	0.8
Tool holder	Coromant Capto C5-PCLNL-17090-12					
Coolant	-					
Cutting data	v_c=160…180 m/min					
	a_p=0.05 mm					
	f=0.08 mm/rev					

3.2. Surface roughness measurement

In the experiments Talysurf Series2 from Taylor Hobson was applied for determination of the roughness parameters and the bearing length ratio of the profile. The computer joint to the measuring machine makes it possible to evaluate the measured values more easily with the application of the Standard Surface Texture Analysis (No 112/2509) and Form Analysis (No 112/2500) software. The measuring instrument can measure not only the profiles which can be determined with the traditional stylus instrument but also it makes the determination of the roughness in three dimensions possible. This is mainly important when the machined surface includes inhomogeneities so these machining errors can be filtered out more easily [1].

3.3. Microhardness and microstructure measurement

For the study of the surface layer the samples were sectioned with an abrasive cutter, mounted in epoxy and polished with fine grit mesh of 180, 240, 400, 600. Then it was followed by polishing on 3 µm and 1 µm polishing paper until mirror-like surface was achieved.

The microhardness measurement was performed with SHIMADZU Micro Hardness Tester. The Vickers hardness measurement was done with load 100 g till 10 s. As the measuring device is connected to a PC, the evaluation of the measured data was performed with software Archive4Image. The microhardness was measured at different depths below the surface. At the same depth in the diagrams to be presented the average values of the measurements are indicated. The hardening depth of the investigated gears was 0.4 mm.

Study on metallographic alterations was performed with Olympus BX60M research microscope, magnification: 1000x, which is fully motorized, equipped with high resolution digital cameras and connected to a PC.

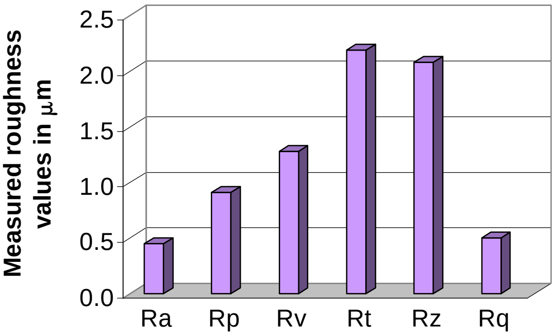
4. RESULTS

4.1. Surface Roughness

4.1.1. Two Dimensional Surface Roughness

In the case of the previous experiments [18, 19] we also experienced that the repetition of irregularities on the hard turned surfaces is regular and roughness profile with regular geometry generates after machining. The surface is smoother, the scatter of the roughness values is relatively low. For the hard turned surfaces the average values of roughness characteristics connected with the height distribution of the profile are presented in Figure 1/a.

a) roughness values



b) bearing length ratio

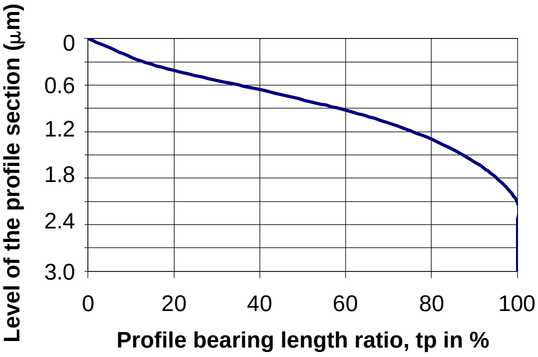


Fig. 1. Measured 2D surface roughness parameters

The value of the average surface roughness (Ra) did not exceed 0.50 µm, while the ten-point-height value of the profile (Rz) of the hard turned bore was 2.1 µm.

Among the roughness characteristics connected to the form of the irregularities, the profile bearing length ratio and the skewness of the profile were investigated. Hard turning generates advantageous profile bearing length ratio and/or curve of that on the machined parts (Figure 1/b). The skewness of the profile possesses negative value (Rsk = -0.52). When regarding the skewness of the profile and the curve of the profile bearing length ratio together, it can be stated that the negative Rsk value indicating better fluid retention property and the advantegeous profile bearing length ratio ensure high wear resistance and proper functional behaviour for the surfaces in their function [1, 6].

4.1.2. Three Dimensional Surface Roughness

When watching the topography gained in the investigation of 3D roughness (Figure 2) it is clear that the surface is smooth and regular. The amplitude or height distribution parameters indicate advantageous values (Figure 3/a) in machining performed by tool with defined PcBN cutting edge.

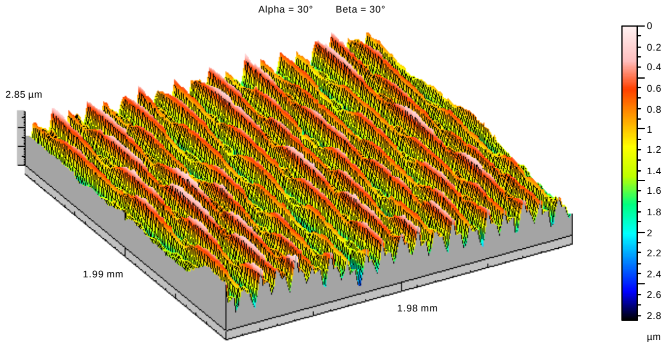


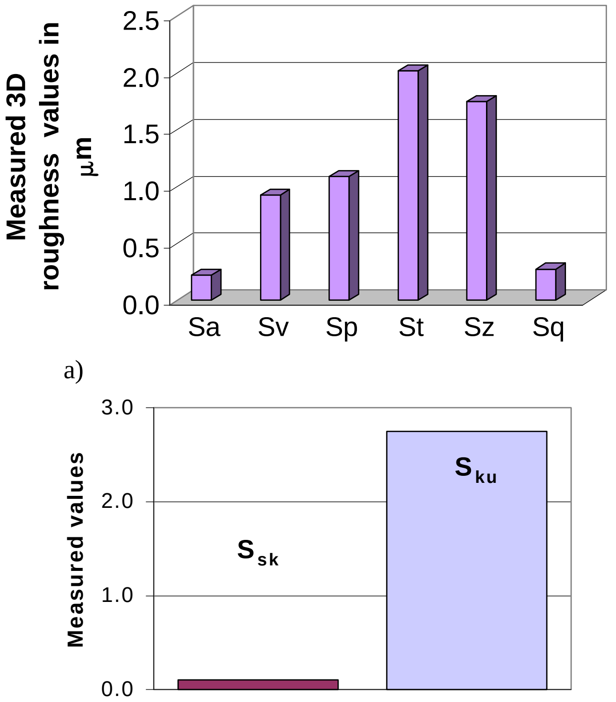
Fig. 2. Topography of hard turned surface

As comparing the two dimensional surface roughness values with the three dimensional one it can be seen that the Ra value is higher in the plane measurement. The two dimensional value of the root-mean-square deviation of the profile (Rq) is almost twice as high as its spatial equivalent (Sq). A root-mean square deviation of the surface (Sq) similarly to the Sa, measures the deviation of surface points from the root mean square of the surface but it is more sensitive to the big surface peak heights and/or valley depths.

The skewness of surface height distribution (Ssk) numarically gives the skewness of the distribution of surface departure density calculated from the root-mean-square of the surface (Figure 3/b) whose equivalent in 2D is the Rsk. The measured value is nearly zero therefore it can be said that the graph of height distribution of the certain surface points is symmetrical [1, 6].

The Sku parameter characterises the kurtosis of height distribution on the surface topography. As this parameter also decribes the form of irregularities well, therefore it can be applied as a functional parameter, too. Its value is Sku = 2.76.

The surface bearing area ratio (Stp) is classified among the functional parameters. The higher surface bearing area ratio indicates better bearing properties and it directly refers to the wearing-in behaviour of the surface.



a)

b)

Fig. 3. 3D amplitude parameters

The hard turned surface shows beneficial surface bearing curve (Figure 4) thus it indicates proper proper bearing properties. For example, at 1.42 µm level of the surface section, the surface bearing area ratio already reaches 60 % when studying the surface bearing curve [11].

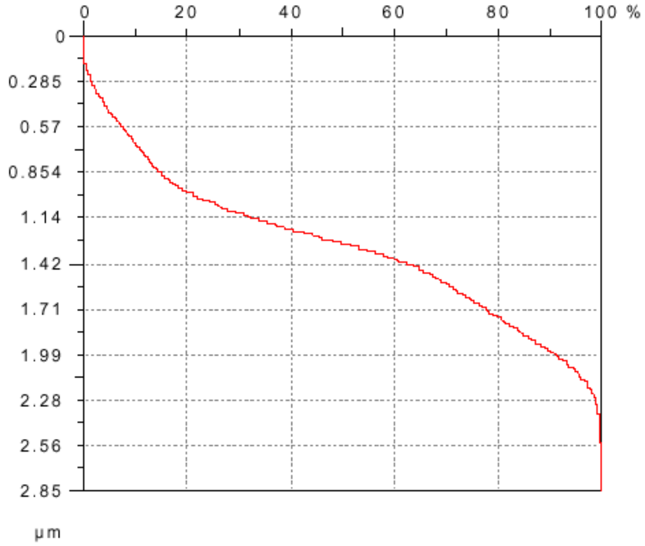


Fig. 4. Surface bearing curves

4.2. Surface Layer Properties

4.2.1. Microhardness

The surface layer of hard turned parts is characterized by hardening up, which is presented well by the performed investigations. In the microhardness measurement of gears' bores with different diameter it was observed that with the reduction of the bore diameter the measure of hardening up increases [17] (Figure 5).

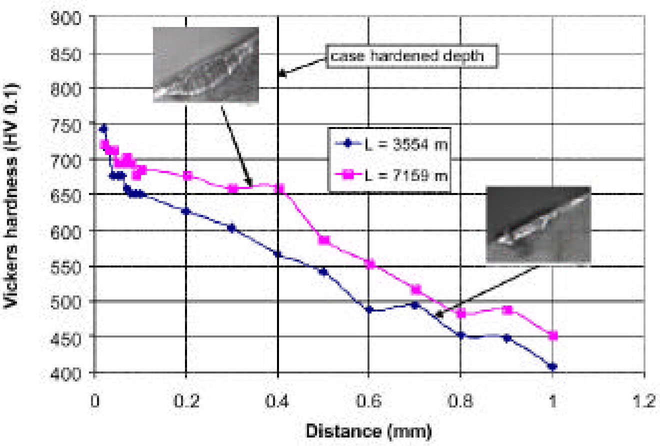


Fig. 5. Microhardness alteration regarding the length of cut

When taking into account the length of cut – namely the tool wear – the surface hardens up better for smaller flank wear (VB = 0.06 mm). For higher flank wear (VB = 0.13 mm) the measure of hardening up is less.

The clearly unsatisfactory industrial acceptance of hard turning can be attributed partly to the insufficient knowledge of the surface quality, mainly the properties of the machined surface layer. Now the microhardness distribution in the machined surface is compared for grinding and hard turning. In Figure 6 the comparison of microhardness distribution is presented for hard turning and grinding. The deviation is advantageous for hard turning because in the case of grinding the microhardness of the surface layer is lower than the microhardness of the bulk material.

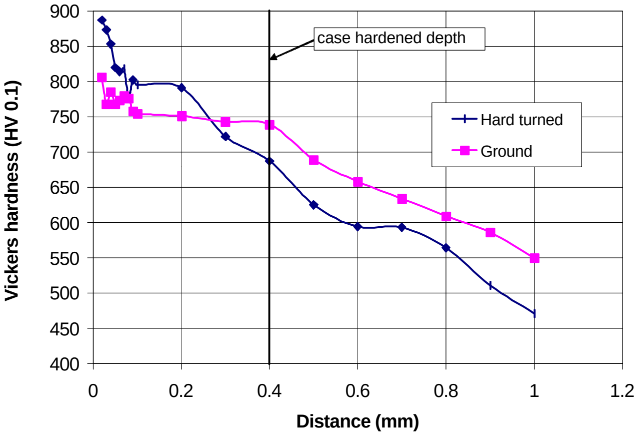
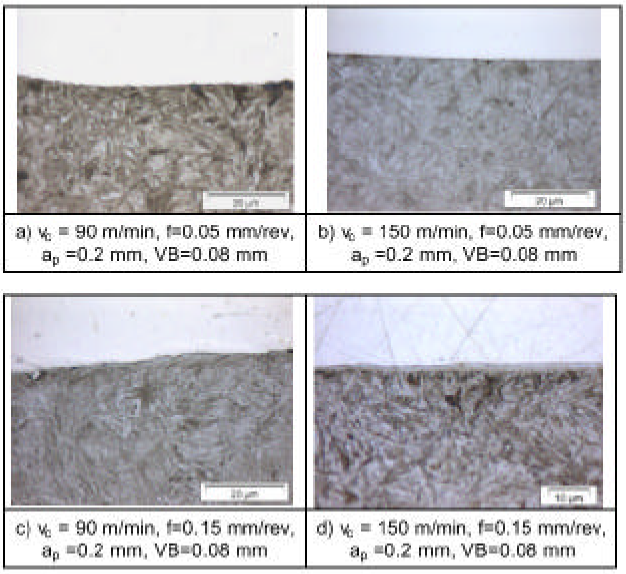


Fig. 6. Microhardness changing in hard turning and grinding

4.2.2. *White Layer*

As a function of the technological data the appearance of white layer was studied. During the experiments the cutting speed and the feed rate varied while the depth of cut was constant. The width of flank wear land was also taken into account and its value was always lower than 0.1 mm. When applying low feed (f = 0.05 mm/rev) independently from the value of the cutting speed, white layer did not appear (Figure 7/a-b). However with the increase of the feed (f = 0.15 mm/rev), white layer appeared in spots when cutting with low cutting speed (Figure 7/c). At high cutting speed (v_c = 150 m/min) appearance of continuous white layer can be obviously observed after hard turning (Figure 7/d).


a) v_c = 90 m/min, f=0.05 mm/rev, a_p =0.2 mm, VB=0.08 mm

b) v_c = 150 m/min, f=0.05 mm/rev, a_p =0.2 mm, VB=0.08 mm

c) v_c = 90 m/min, f=0.15 mm/rev, a_p =0.2 mm, VB=0.08 mm

d) v_c = 150 m/min, f=0.15 mm/rev, a_p =0.2 mm, VB=0.08 mm

Fig. 7. White layer in cutting of hardened steels

The thermo-mechanical effects occurring in cutting determine the generation of the white layer. According to the performed investigations it is clear if the technological data is chosen well, the appearance of this layer can be avoided. Therefore the future research work is to reveal exact explanation, under which conditions the white layer appears or can be avoided.

5. CONCLUSIONS

The low roughness values, the form repeating regularly the higher constancy of the 3D amplitude and spatial characteristics, the hard turned surface can be qualified proper and indicates good fluid retention ability. The hard turned bore possesses advantageous bearing surface thus it represents beneficial properties from the point of view of friction and wear resistance.

The microhardness investigations indicate hardened up surface which is advantageous in the functional behaviour of the parts under significant loads.

In the material removal processes – mainly in the cutting of hardened steels – the thermal and mechanical effects can influence the surface integrity of the parts and their life time, too.

Under the proper selection of the technological data, the changes in the surface layer have advantageous effect on the properties of the layer thus on the life time of the parts, too. However, the condition of the increase of the life time is to avoid the appearance of the white layer.

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