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SURFACE ROUGHNESS PRODUCED BY HARD TURNING WITH PCBN TOOLS

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Abstract: *This paper investigates surface finish in continuous dry turning of hardened steel when using PCBN tools. The surface profiles (2D arrangement) and surface topography (3D arrangement) generated during hard turning operation on a EN 41Cr4 low chromium alloy steel, heat treated to the hardness of 58 HRC, were evaluated. This paper introduces the multi-parameter characterization of the surface when cutting with different tool materials.*
Key words*: hard turning, surface roughness, PCBN tools.*

1. INTRODUCTION

The main applications for hard turning are finishing processes, which are characterised by a high form and size accuracy, high surface finish and surface integrity of the workpiece [1].
Hard turning can provide a relatively high accuracy for many hard parts but sometimes important problems occur with surface finish. Moreover, hard turning can influence the workpiece surface microstructure by generating undesirable residual stress pattern and brittle, "white layer", which reduces fatigue life of turned surfaces [2].
Hard machining has become possible by using the range of advanced cutting materials such as PCBN. Low depth of cut, small feed rate and the large cutting edge radius are typical finishing conditions in hard turning with PCBN tools. The cutting tool can produce stable surface finish but cutting tool geometry is one of critical process parameters particularly when cutting speed exceeds the values of 100m/min.
In this study, finish turning tests were carried out using a hardened low chromium steel and cutting inserts – coated and uncoated PCBN tool. The assessment of surface features in 2D and 3D arrangement is presented in relation to their being produced by coated and uncoated tools.

2. EXPERIMENTAL PROCEDURE

The main aim of the study was the assessment of the surface finish produced during turning with coated and uncoated PCBN tools. Turning tests were performed on a high rigidity lathe NEF 400. Bars of a low chromium alloy steel equivalent to EN41Cr4 hardened to 58 HRC were used. They were 90 mm long with an external diameter of 26 mm.
The cutting tool material was Sandvik Polycrystalline Cubic Boron Nitride - CB20 and 7020. The inserts conformed to the ISO code TNGA 160408 S1020 and the tool holder DTGNR 2525 M 16. Cutting conditions were selected according to the recommendations provided by cutting tools manufacturers. Thus, triangular inserts with the same nose radius of 0.8 mm were used. The cutting speed was kept at 165 m/min with feed rate of 0.15 mm/rev.
After each turning test surface finish was measured in the 2D and 3D arrangements. The three-dimensional topographic maps of the machined surfaces were produced using coherence correlation interferometry technique. Two-dimensional data were selected using confocal technique.
A set of the 2D roughness parameters was determined by simple roughness measurements using a Taylor Hobson CLI

2000 instrument. Moreover, 3D measurements were carried out by means of Talysurf CCI 6000 profilometer. In consequence, the analysis of the surface geometrical structures was done using both profiles and 3D topographies of the surface. Both 2D and 3D parameters, were taken into account [3,4].

3. RESULTS AND DISCUSSION

3.1. Tool geometry and wear

For cutting tests, uncoated and coated (with a TiN layer, 1 μm thick) inserts were selected. Geometry of both wedges was similar (chamfer normal rake angle $\gamma n = -20°$, chamfer width: 0.1 mm, honing edge radius = 0.03 mm). The cutting edge inclination angle of the insert is $\lambda s = -6°$, and the normal rake angle was $\gamma n = -6°$.

Wedges underwent analysis in the initial phase of their work, when the tool nose was still coated with the TiN layer. The wedges cut for 48m, which took 18 seconds of cutting. After this time durability of the wedge was not distorted, the wear rate was insignificant and occurred only on the main flank. Figure 1 presents a view of the flank from the wedge's side.

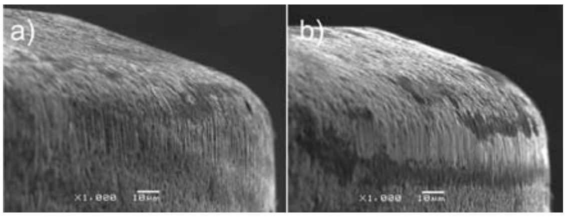


Fig. 1. Tool flank wear for CB20 (a) and 7020 (b) cutting tool material

In case of CB20 the wedge' wear was almost unnoticeable. For 7020 wedge the wear is outlined by the changeability of material properties in SEM images. Nonetheless, the change in tool geometry is visible only in the area of tool edge rounding.

3.2. Machined surface

Theoretical research on surface roughness focuses on kinematic-geometric mapping of tool nose. Cutting takes place through part of the rounded tool nose. The value of tool nose radius determines an almost flat stretch parallel to the surface of a length similar to the value of the feed rate (Fig.2).

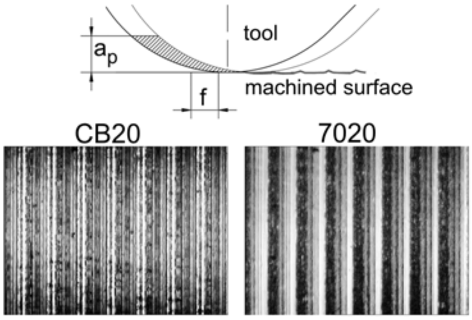


Fig. 2. Schema of producing machined surface and machined surface image

Theoretical roughness, calculated for cutting conditions, is estimated to be 0.807μm. The measured roughness is higher than the theoretical value. The reason of that is the minimal irremovable layer of the cut material. When the wedge is unable to remove the material then it is deformed or removed as microcutting, scratching or ploughing. During microcutting furrows are detected in the machined material through exposition of unevenness of the cutting edge, which goes into the material, cuts its parts off during relative movement, piles them up and tears them off. Scratches appear in the machined material because of the protruding element of unevenness of the cutting edge. The phenomenon of scratching is a transitional stage. Ploughing is indenting projection of the cutting edge into the machined material and plastic expression of a furrow in it during the relative movement. The material expressed from the furrow is piled up along one of its sidewalls. Figure 2 presents the image of machined surface produced in turning with PCBN tools. Development of machined surface demonstrates very different mechanisms when considering coated and uncoated wedges. Further considerations concern the description of the development of machined surface in 2D and 3D arrangements.

3.3. Surface roughness analysis – 2D

Due to repeatability of the profile at the distance of the feed rate's value, part of the profile of a feed rate length can be distinguished in such a way that 'outline of the wedge' – the basic shape of unevenness, is obtained (Fig.3).

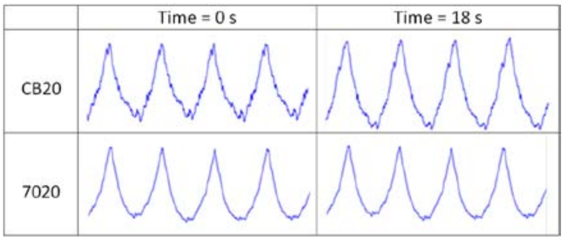


Fig. 3. Machined surface roughness profile

Comparing proportions of heights of the unevenness with length of the basic shape of unevenness - 5 µm of height to 150 µm of length of the feed rate - it can be noticed that it is a tiny, almost flat part of the wedge, which is printed on the surface and which remains unchanged for a long time – despite change of the wedge's geometry of the main flank and rake face.

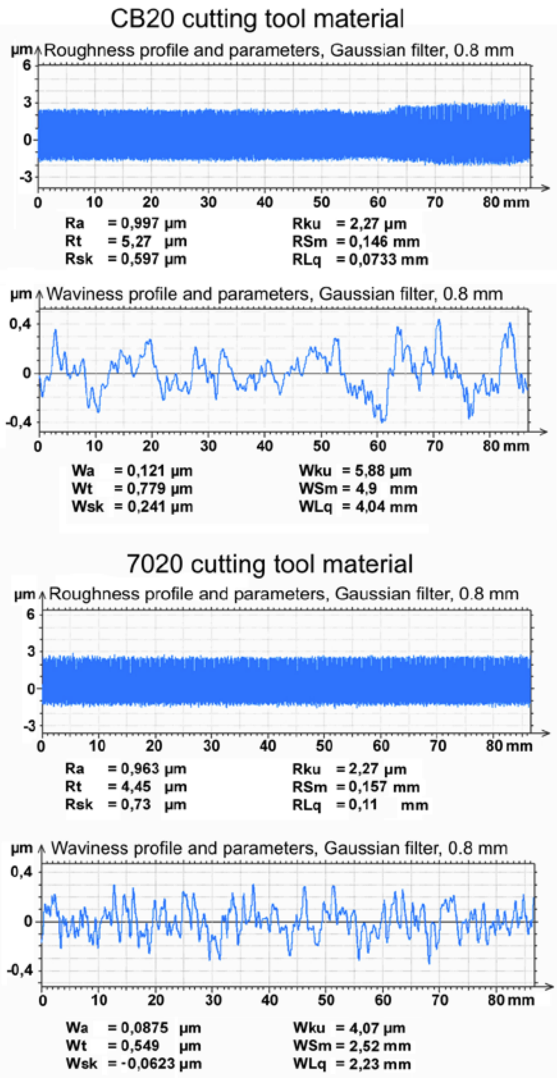


Fig. 4. Machined surface roughness and waviness profiles and parameters

Analysis of roughness profiles created by CB20 and 7020 cutting tools makes observation of differences (Fig.4). The initial phase of cutting is very similar; parameters are almost identical. The lesser change of cutting tool geometry influenced the surface roughness profile. Rt parameter increased nearly 1µm so that the averaged value for the whole profile is equal to 5.27µm.

Analysis of surface waviness profile demonstrates significant differences for all the parameters. Differences in this case take from the difficulties in cutting with negative rake angle and large and developed cutting edge.

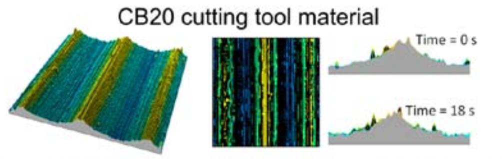
3.4. Surface roughness analysis – 3D

Analysis of topography displayed in Figure 5 demonstrates for both of the cases very smooth surface. The ridges after the tool pass are almost identical. The range of height is approximate, though it is smaller for the surface shaped by the coated wedge. The differences are barely noticeable for most of the amplitude, area & volume, and spatial parameters. Therefore, their description is omitted.

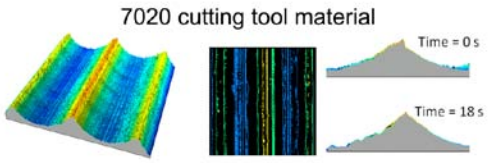
Observation of the contour maps of the surface and then the layout of the unevenness shows visible differences. Concentration of lines and points on the contour map is different. Greater randomness of the surface is visible especially in case of surface created by uncoated wedge where cutting edge is more developed. To describe the visible differences more thoroughly several parameters was chosen (Fig.5).

Mean material volume ratio (Smmr) was selected as the first parameter. It is a parameter describing the total volume of material of the surface obtained by measuring the space between an imaginary horizontal plane at the minimum altitude of the surface and the points of the surface. The higher value of Smmr for CB20 cutting tool material (>3µm^3/µm^2) indicates that in this case the material volume will be subjected to higher wear.

Density of summits (Sds), and root-mean-square slope (Sdq) were selected for the reason that they are able to describe the susceptibility to abrasive wear. Values of parameters for uncoated tools are nearly twice the coated. These and subsequent parameters confirm greater complexity of machined surface for CB20 than 7020.



Parameter	Time = 0 s	Time = 18 s
Smmr ($\mu m^3/\mu m^2$)	3.69	4.35
Sds (pks/mm^2)	319799	380241
Sdq ($\mu m/\mu m$)	1.06	1.3
Ssc ($1/\mu m$)	3.82	4.37
Sdr (%)	33.1	47.8



Parameter	Time = 0 s	Time = 18 s
Smmr ($\mu m^3/\mu m^2$)	2.99	2.86
Sds (pks/mm^2)	143142	143158
Sdq ($\mu m/\mu m$)	0.48	0.47
Ssc ($1/\mu m$)	2.77	2.59
Sdr (%)	9.41	8.95

Fig. 5. Topography images and parameters of machined surface

Arithmetic mean summit curvature (Ssc) enables to know the mean form of the peaks: either pointed, either rounded, according to the mean value of the curvature of the surface at these points. The value of Ssc for CB20 cutting tool material is greater and increases with cutting time.
Developed interfacial area ratio (Sdr) describes the complexity of the surface thanks to the comparison of the curvilinear surface and the support surface. A completely flat surface has a Sdr near 0%. Sdr is of 33.1% for CB20 cutting tool material and only 9.41 for 7020 cutting tool material. The difference increases with cutting time.

5. CONCLUSIONS

Based on the experimental results, 2D and 3D parameters of the surface produced by hard machining with PCBN coated and uncoated tools were selected and analysed.

In general, hard turning with PCBN tools provide very smooth and uniform surface. Hard turned surfaces in both cases were produced with the positive values of skewness and kurtosis less than 3. Differences were better distinguished in waviness profile and parameters.
Complexity of the textures for both surfaces was described with five different parameters. 3D images and adequate contour maps of the surfaces generated by hard turning allow distinguishing mixed-anisotropic textures when the random part was significantly greater for CB20 cutting tool material.

6. REFERENCES

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