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EVALUATION OF SURFACE TOPOGRAPHY AND BEARING PROPERTIES OF HARD TURNED SURFACES USING DIFFERENTLY SHAPED PCBN TOOLS

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Summary

This paper deals with hard turning using conventional and wiper polycrystalline cubic boron nitride (PCBN) tools. 3D surface topographies and bearing area curves were determined and compared after hard turning with differently shaped cutting tools. Machined parts were made of a 100Cr6 (AISI 5210) hardened bearing steel with Rockwell hardness HRC=60 ± 1 HRC.

Keywords: hard turning, wiper geometry, bearing area curve, surface topography

Analiza topografii i nośności powierzchni po obróbce na twardo przy użyciu narzędzi z PCBN

Streszczenie

W pracy przedstawiono analizę wyników badań procesu obróbki twardych materiałów po toczeniu ostrzami skrawającymi o geometrii konwencjonalnej i wiper wykonanych z PCBN. Określono krzywe udziału materiałowego powierzchni oraz topografię powierzchni po obróbce na twardo stali łożyskowej 100Cr6 (AISI 5210) wg DIN 17230 o twardości HRC 60±1.

Słowa kluczowe: obróbka na twardo, geometria wiper, krzywa udziału nośnego, chropowatość powierzchni

1. Introduction

In its broad definition, hard machining is the machining of parts with a hardnes of above 45 HRC, although most frequently the process concerns hardnesses of 58 to 68 HRC. The workpiece materials involved include various hardened alloy steels, tool steels, case-hardened steels, superalloys, nitrided irons and hard-chrome coated steels, and heat-treated powder metallurgy parts. It is mainly a finishing or semi-finishing process where high dimensional, form and surface finish accuracy have to be achieved.

The conventional solution to finishing hardened steel parts has been grinding, but there are a number of clear benefits of the machining of hard parts

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with cutting tools. These have justified many existing applications that are growing in number, especially involving turning, boring, and milling. Hard turning was early recognized and pioneered by the automotive industry as a means of improving the manufacturing of transmission components. Gear-wheel bearing surfaces are typical examples of early applications converted from grinding to hard machining using cutting inserts made of polycrystalline cubic boron nitride (PCBN) [1, 2].

There is a possibility to use different cutting tool geometries to perform hard turning. Wiper geometry (Fig. 1) differs from the conventional geometry in the shape of minor cutting edge. This WIPER edge replaces the minor cutting edge and reduces its cutting tool angle to a minimum, and as a result it automatically reduces the theoretically computed surface roughness by 2 to 4 times [3].

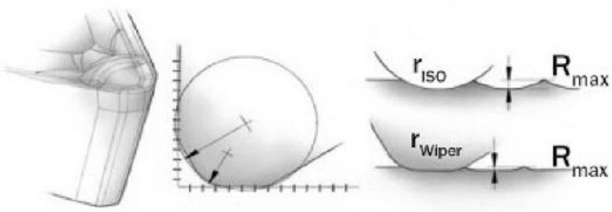


Fig. 1 Wiper geometry and corresponding surface finish [4]

Cutting tool geometry influences surface profile and surface roughness, among other things. It is necessary to take into consideration an evaluation of the bearing area curve (BAC) when dealing with functionality of the machined surface. Bearing area is a real area of contact and may be approximately obtained from a surface profile or a surface map. The BAC was first proposed by Abbot and Firestone (1933) and it is also called Abbot – Firestone curve or simply Abbot curve. It gives the ratio of material total length at any level, starting at the highest peak, called the bearing ratio or material ratio, as a function of level [5].

This article deals with comparison of the BAC's created for conventional and wiper geometry when machining with the same cutting conditions. Difference of use of these two geometries is also observed in the 3D surface topographies, which are related to the 3D surface roughness parameters.

2. Experimental investigations

The workpiece material was the hardened bearing steel-grade 100Cr6. Its chemical composition is specified in Table 1.

Table 1. Chemical composition of 100Cr6 steel

Element contents, wt %									
Cr	**C**	**Si**	**Mn**	**P**	**S**	**Ni**	**Cu**	**Mo**	**Fe**
0.98-1.05	1.40-1.65	0.15-0.35	0.25-0.45	≤ 0.027	≤ 0.02	0.23	≤ 0.25	≤ 0.1	balance

Rockwell hardness of the workpiece material was 60 ± 1 HRC. The bar shown in Fig. 2 was sectioned into six parts in order to generate the surface topographies related to six different feed rates (0.04-0.4 mm/rev) specified in Table 2. PCBN cutting tool inserts with the nose radius of r_ε = 0.8 mm used for machining were made by Seco Tools company. The same machining parameters were used for hard turning operations with conventional and wiper cutting tools.

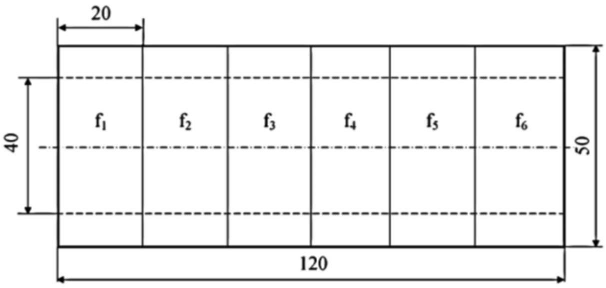


Fig. 2 The sketch of machined workpiece.

Cutting parameters were selected in such a way that the cutting speed was constant at v_c = 150 m/min and the depth of cut was constant at a_p = 0.25 mm but the feed rate was varied from 0.04 mm/rev to 0.4 mm/rev (6 different feed values were selected) as shown in Table 2. This is based on the fact that feed rate predominantly influences the surface roughness in machining operations. Hard turning operations were carried out on the turning machine OKUMA-GENOS L200. Feed values were selected based on the technological capabilities of the lathe.

Table 2. Cutting conditions used for the hard turning process

Cutting parameter							
a_p, mm	**v_c, m/min**	**f_1, mm**	**f_2, mm**	**f_3, mm**	**f_4, mm**	**f_5, mm**	**f_6, mm**
0.25	150	0.04	0.1	0.14	0.2	0.28	0.4

3. Experimental results

As mentioned in Section 2, 3D surface topographies and associated material ratio (bearing area) curves were evaluated for hard turned surfaces generated by differently shaped PCBN cutting tools and the hardened workpieces with the hardness 60 ± 1 HRC.

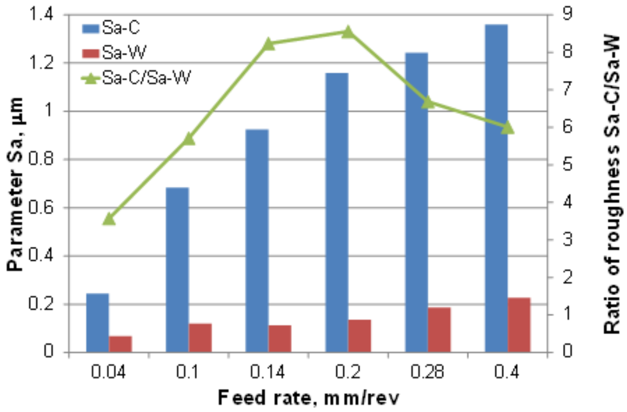


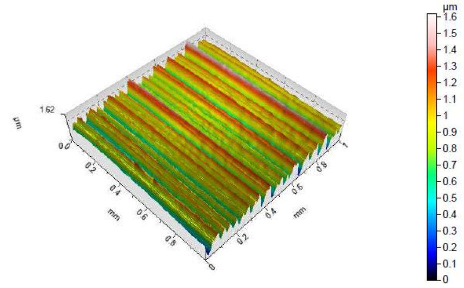
Fig. 3. Changes of the Sa parameter after hard turning using conventional and wiper cutting tools

First of all, the appropriate values of the arithmetic mean height Sa were compared in Fig. 3. It is evident in Fig. 3 that surfaces machined with wiper inserts have distinctly higher surface roughness for all feed applied and the ratio of Sa-c/Sa-w (Sa values for conventional and wiper tools respectively) ranges from about 3 for the lowest feed of 0.04 mm/rev to above 8 for the medium feeds and to about 6 the highest feed applied of 0.4 mm/rev. These data suggest that wiper tools are most very effective in finish HT operations with medium feeds in terms of reduction of the surface roughness [6]. Moreover, the values of Sa and Sz roughness parameters are specified in Fig. 4-6.

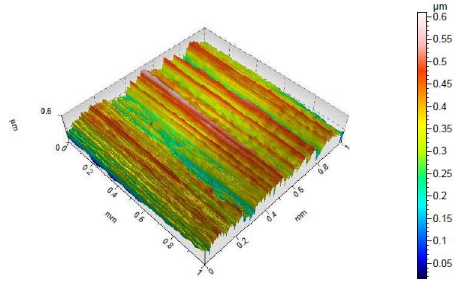
Figures 4-6 show the surface topographies and overlays of the surface profiles obtained for the feed of 0.04, 0.14 and 0.4 mm/rev respectively. It is clear in Fig. 4 that wiper tools smoothed the surface and the surface with blunt irregularities is generated. The ratio between the values of the maximum height Sz is equal to 2.5.

Surface topographies for the feed of 0.14 mm/rev are shown in Fig. 5. For this case the value of the Sz parameter obtained for turning with a conventional PCBN tool is four times higher than Sz obtained for wiper geometry.

a) Sa = 0.24 μm, Sz = 1.62 μm



b) Sa = 0.07 μm, Sz = 0.61 μm



c)

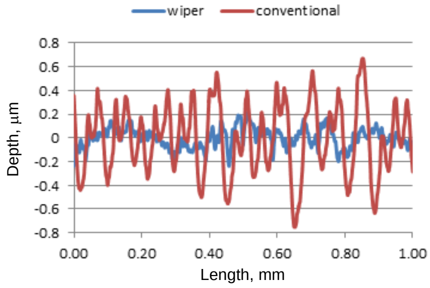
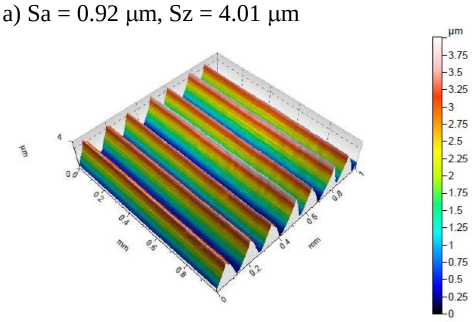
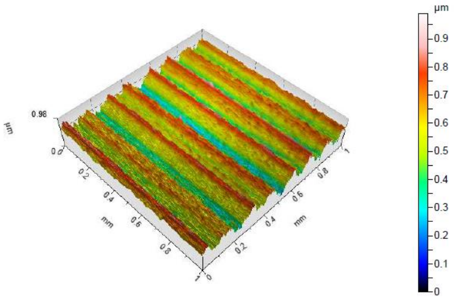


Fig. 4. Surface topographies and surface profiles obtained for feed $f = 0.04$ mm: a) conventional (C), b) wiper (W) and c) difference between surface profiles for C and W tools

a) Sa = 0.92 μm, Sz = 4.01 μm



b) Sa = 0.11 μm, Sz = 0.99 μm



c)

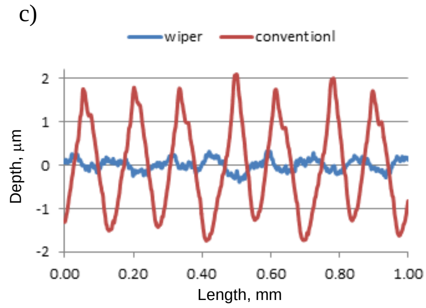


Fig. 5. Surface topographies and surface profiles obtained for feed $f = 0.14$ mm: a) conventional (C), b) wiper (W) and c) difference between surface profiles for C and W tools

The evaluated surface characteristics for the highest feed value used of 0.4 mm/rev are shown in Fig. 6. In this case the Sz parameters is reduced about 5 times in comparison to conventional hard turning. The roughness data presented in Figs. 4-6 confirm that wiper PCBN tools are very effective in finish hard turning because they allow to substantially increase the productivity which is very important in mass production of hardened parts (for instance in the automotive industry).

a) Sa=1.36 μm, Sz=8.23 μm b) Sa=0.23 μm, Sz=1.60 μm

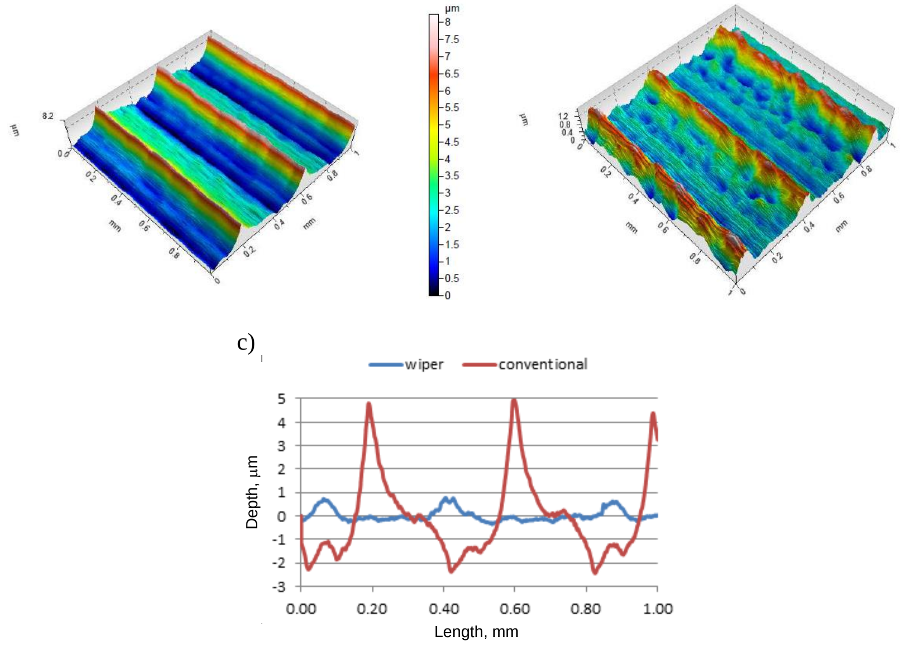


Fig. 6. Surface topographies and surface profiles obtained for feed f = 0,4 mm: a) conventional (C), b) wiper (W) and c) difference between surface profiles for C and W tools

Figure 7 presents three graphs for illustration of the improvement of the bearing area curve with the increase of the feed (where: c - segment length of the elementary level for a complex intersection c in %, Rmr (c) - parameter relative for the material roughness profile to the level of c in %). Surface topography expresses also difference between the use of conventional geometry or wiper geometry for hard turning because the surface shape is influenced by the feed value.

In general, it is possible to achieve convex or concave Abbot curve. If it is more concave, it will be better for the workpiece functionality. The Abbot curves were generated for surfaces machined with varying feed rate. These curves are more convex with an increase of the feed, and it was observed for both geometries. Very similar curves were achieved, when using the lowest and the highest feed values (Fig. 7 a and c). The main difference in the shape of these curves was achieved, when using a medium feed of 0.14 mm, when it was still concave for the wiper geometry, but it started to be convex for the conventional geometry (Fig. 7b). The producer recommends wiper cutting inserts to have the best performance when using higher feeds. This fact is also sum up from this experiment.

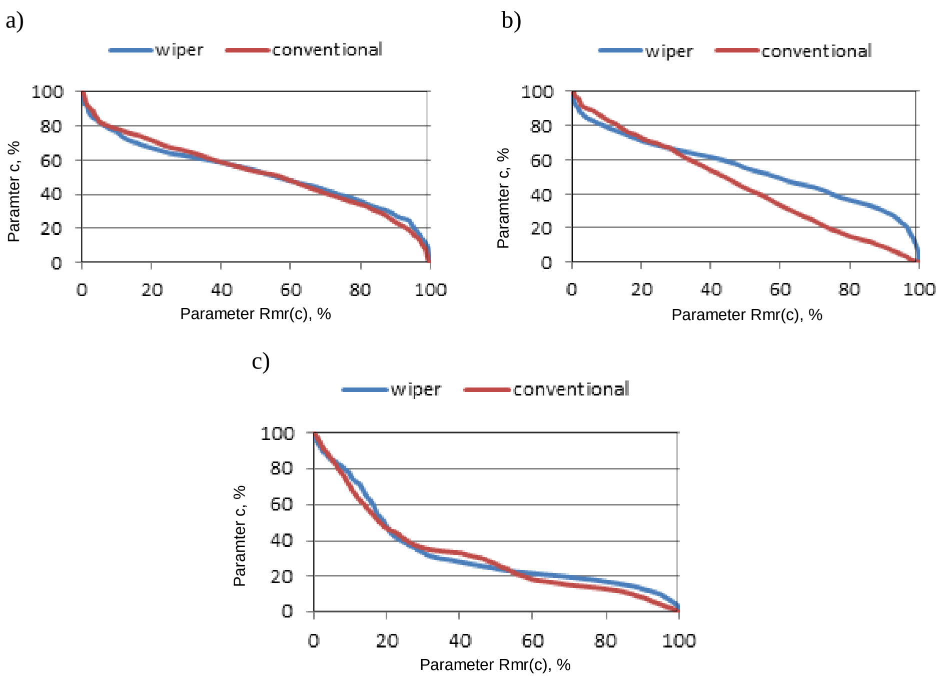


Fig. 7. Bearing area curves for different feed rate: a) *f* = 0,14 mm/rev; b) *f* = 0.14 mm/rev, c) *f* = 0.4 mm/rev

Figure 8 presents the map of kurtosis (*Sku*) versus skewness (*Ssk*) for all surfaces generated by conventional and wiper PCBN tools. It is evident in Fig. 8 that wiper tools generate surfaces with negative skewness *Ssk* (see markers at left side) apart from the higher feed rates of 0.28 and 0.4 mm/rev. On the other hand, surfaces produced by inserts with rounded corner of 0.8 mm radius have positive values of *Ssk* parameters and as a result worse bearing properties.

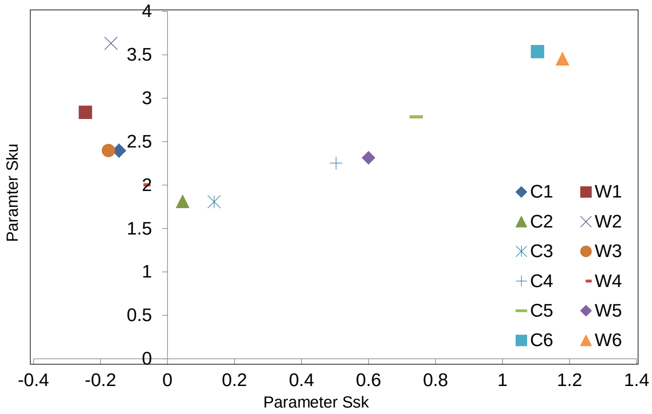


Fig. 8. Map of normalized kurtosis (*Sku*) versus skewness (*Ssk*) for hard turning. Symbols in map: C-conventional turning, W-wiper turning. Machining conditions: C1-W1-f = 0.04 mm/rev, C2-W2-0.1 mm/rev, C3-W3-f = 0.14 mm/rev, C4-W4-f = = 0.2 mm/rev, C5-W5-f = 0.28 mm/rev, C6-W6-f = 0.4 mm/rev

Conclusion

Bearing area curve is very important to evaluate the functionality of the machined surface. The evaluation of the Abbot curve lies in the fact if the shape of the curve is convex or concave. If it is more concave, then it will be highly functional. Conventional geometry provides very similar results in comparison to wiper geometry when using the lowest and the highest feed value. The only difference is in use of the middle feed value (0.14 mm), when for conventional tool the bearing area curve becomes convex and wiper tools produce the BAC with a concave shape. This facts show an advantage in the use of wiper geometry over hard turning when dealing with workpiece functionality.

Acknowledgments

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