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Measurement of tool flank wear with the use of white light interferometer

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Abstract

Tool geometry is one of the key factors influencing the quality of the cutting process. Usually the geometry is described for a new tool and the changes in it during cutting are explained with the use of tool wear indexes. They are quite easy to measure when the wear is significant. However, for the finishing processes the location of tool edge and the roughness of the tool edge are the most important factors, which are difficult to measure mainly because of a very developed surface of wear land with a number of difficult to measure points. In the paper, the Talysurf CCI 6000 was used to measure tool cutting wedge geometry, flank wear and roughness of the cutting edge. Measurement of tool irregularities with the use of CCI 6000 was rapid but its application was limited for measurement tool geometry in a state of wear.

Keywords: tool geometry, flank wear, roughness of the cutting edge rounding.

Pomiar zużycia ostrza skrawającego interferometrem światła białego

Streszczenie

Geometria narzędzia jest kluczowym czynnikiem wpływającym na jakość procesu skrawania. Geometria podawana jest dla narzędzia nowego, natomiast zmiany na ostrzu podczas jego pracy opisywane są za pomocą wskaźników zużycia ostrza zdefiniowanych w normie ISO 3685. Wyznaczenie wartości wskaźników zużycia ostrza nie nastręcza wielu problemów, gdy wielkość ta dotyczy zużycia na granicy trwałości narzędzia [1-5]. Natomiast dla obróbki wykończeniowej decydującym o jakości procesu jest położenie krawędzi skrawającej (wymiar geometryczny przedmiotu) oraz chropowatość krawędzi skrawającej (mikrochropowatość powierzchni obrobionej) [6-9]. Charakterystyki te są trudne do zmierzenia ze względu na rozwiniętą powierzchnię zużycia ostrza oraz występujące mikropowierzchnie o znacznym nachyleniu. W artykule zaprezentowano pomiar geometrii narzędzia, zużycia na powierzchni przyłożenia oraz chropowatości powierzchni obrobionej przy zastosowaniu Talysurf CCI 6000 [10]. Pomiar przy użyciu CCI 6000 okazał się niezwykle szybki i dokładny. Ze względu na ograniczony zakres pomiaru wielkości, zarówno w pionie jak i w poziomie, dominującym czynnikiem określającym możliwości pomiarowe okazało się precyzyjne ustawianie ostrza podczas pomiaru.

Słowa kluczowe: geometria narzędzia, zużycie na powierzchni przyłożenia, chropowatość na zaokrągleniu krawędzi skrawającej.

1. Introduction

Superhard tool materials such as polycrystalline cubic boron nitride (PCBN) enable the hard turning, which can be an alternative to grinding processes. Of the presently available cutting tool materials, PCBN is the best candidate and is presently being widely used in hard turning. Due to the high material cost of PCBN tools and rapid tool wear, better understanding of the wear mechanisms and patterns in hard turning are needed to optimize cutting conditions and tool geometry to alleviate tool wear.

In machining of hardened steels with PCBN cutting tools the cutting takes place along chamfered edges on the nose of cutting tools. Changes in the cutting geometry that result from crater wear and flank wear can be substantial and they form on both the flank and rake faces of PCBN cutting tools.

Flank wear has been studied more frequently because it is the main tool life criteria defined in the ISO 3685 standard [1-5]. A tool is considered to have reached its life if the maximum width of flank wear land or average flank wear is of certain value. In finishing operations where the depth of cut is small, the flank wear land width in the nose area is a more meaningful parameter for assessing tool life, particularly when surface finish quality is the main criterion. Flank wear in a zone of tool nose rounding is visible from a top of the nose area of the cutting tool and appears as nose radius wear. The nose radius wear is caused by material lost from the nose area, by shortening of the tool.

Obviously, both the cutting edge geometry and tool wear have an important effect on the cutting process. Tool wear results in undesirable effects like loss in dimensional accuracy, decreased surface integrity, and increase of chatter during the cutting process [6, 7]. For these reasons, it is very important to evaluate tool wear mechanisms in hard turning because it can guide process optimization and tool life improvement.

This research aims to describe the methodology of identification of the wear of PCBN tools. For two different tool materials the cutting tests were performed which led to achievement for the tools the initial state of wear. The cutting part was evaluated with scanning electron microscopy to ensure the reference results. Then the white light microscopy was used to measure the tool geometry, wear of the edge rounding and roughness of the tool edge. These parameters were selected because they affect the cutting process by changing the contact conditions between the cutting tool and the workpiece. The effects of tool wear are especially important for precision machining applications where the cutting dimensions are comparable to the dimensions of resulting wear scars.

2. Model of tool flank wear

As the time of cutting passes, the traces of wear can be noticeable both on flank and rake faces. The image of these traces on the surface depends on the geometry of the active part of the cutting tool and cutting conditions. The cutting edge of an insert is subjected to a combination of high temperatures and stresses, which cause chemical reactions. Mechanisms of tool wear depend on the tool and workpiece material combination, cutting geometry, the environment, and mechanical and thermal loadings encountered. The main observed wear patterns are crater wear, flank wear, depth of cut notching and nose wear. Also thermal shock cracks, chipping and tool breakage are possible for PCBN tools.

Flank wear occurs primarily by rubbing of the flank face against the workpiece surface and can be minimized by raising the tool hardness under elevated temperatures. The three mainly distinguishing zones can be visible with the different trace creating mechanics on the worn out edge [8, 9]. Figure 1 shows the shapes of the wear traces when PCBN tool is used accordingly the producer recommendations.

In zone I, when the wear increases, the characteristic point appeared in which cutting edge crosses the strained layer. The position of the point designates the cutting depth. The concentrated wear traces appear around this point. The width is concerned with the thickness of the consolidated layer. The higher temperature in this zone and the airflow from the free way of the cutting part increase the wear.

In zone II, the rubout is in a shape of the rectangular band. The width of this band increases with cutting time.

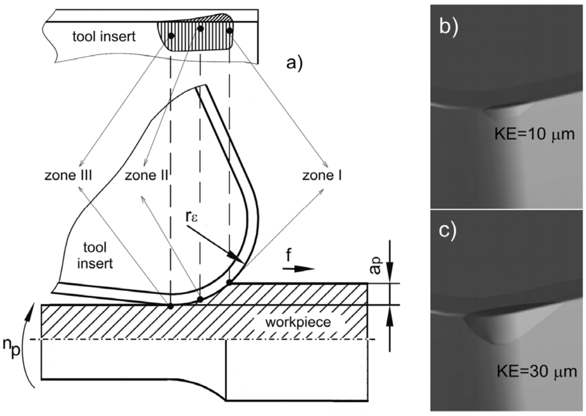

Fig. 1. Wear traces on the tool flank
Rys. 1. Ślady zużycia na powierzchni przyłożenia

In zone III, the outline of wear is the result of complex mechanisms. For the edge of the radius r_ε>0 the cutting depth changes as $h < h_{\min}$, particularly when the feed is small that is characteristic for finishing treatment. The outline of tool wear being the result of shortening of the tool in this case is in a form of ellipse (Fig. 1 b, c).

3. Research methodology

Steel (EN 41Cr4) was chosen as the workpiece material. The average hardness value of the given sample was 58HRC. Before the cutting, the machined object was thoroughly prepared to limit other influences except those expected. The research was realized on a stiff machine tool using PCBN uncoated wedges and wedges covered with a thin TiN layer. Sandvik Coromant TNGA 16 04 08 S01020 cutting inserts were applied. The wedge's material was labeled as 7020 – the coated wedge and CB20 – uncoated wedge. The cutting wedges were placed in DTGNR 2525 M 16 tool holder. The turning tests were realized without the coolant for constant cutting speed.

3.1. Machined material

The machined material used in the research was steel EN 41Cr4. The steel was hardened in water of temperature 850 °C. Measurement of the steel's hardness was carried out in laboratory conditions using Rockwell's method. After the steel was hardened, it achieved the average hardness of 58HRC. The typical chemical composition of steel is 0.44% carbon, max 0,3% nickel, 0.8-1.1% chromium, 0.5-0.8% manganese, and 0.17-0.37% silicon. The applied rolls were 90 mm long and with the diameter of 26 mm.

3.2. Cutting tools

CBN inserts of ISO TNGA 160408 S code were used in the research. These were uncoated and coated (with a TiN layer, 1 um thick) inserts. 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 $\gamma n = -6°$.

EDS analysis of the new uncoated wedge reveled such elements as B, N, C, Ti (88%) in it, and Al, Co and W (12%) in smaller quantities. EDS analysis of the coated wedge revealed a TiN coating - Ti (75%) and N (25%). For 7020 tool material, the thin TiN coating thoroughly covers the CBN structure. Microstructure grains have a diameter of 0.5 to 2 µm. For CB20 cutting tool material, CBN, Co, W and Al grains are the size of 1 to 2 µm; the binder is TiCN.

3.3. Experimental procedure

As was already mentioned, the research was performed using CNC NEF 400. The attempts of continuous cutting were realized for speed of cutting 165 m/min, feed rate 0.15 mm/rot and depth of cut 0.2 mm.

3.4. Wear of the tool

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 48 m, 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. In case of CB20 (Fig. 2) the wedge' wear was almost unnoticeable. Minor single bright points show quality of the cutting edge. The set of similar photos for 7020 wedge shows more significantly the wedge's wear. Various temperature discolorations are visible on the layer. In the flank photo a small uniform abrasion is visible on the side of the cutting edge.

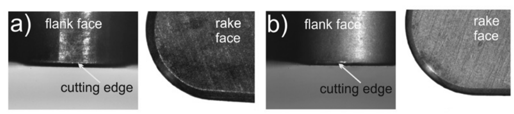

Fig. 2. Digital images of tool wedge taken by Baty Venture 2010, table 200x100x160, head TP20 Renishaw for a) CB20, b) 7020 cutting tool material
Rys. 2. Obrazy cyfrowe ostrza zebrane przez Baty Venture 2010, stolik 200x100x160 głowica TP20 Renishaw, dla materiału ostrza: a) CB20, b) 7020

3.5. Measurement system

Talysurf CCI combines the surface imaging quality with the fast scanning, high accuracy measuring capability of a surface profiler. It is based on coherence correlation interferometry. This technique uses the full band of optical frequencies. The measurement results contain very low level of data errors due to the appropriate selection of the optical resolution and the size of a pixel. The system uses advanced computer algorithms to record the exact vertical position for each point on the surface with sub-nanometer resolution. The limitation for the instrument is mainly the spatial range of measurements. Correct set-up of a cutting wedge in relation to the optical axis of CCI 6000 enables to measure the parameters of tool geometry, wear and roughness of cutting edge.

The principle of operation of the CCI system, widely described in [6], is that the upper beam splitter directs a light beam from the light source towards the objective's lenses. The lower beam splitter splits the light into two separate beams. Each beam travels a separate optical path length. The first beam is projected on a small reference surface located inside of the objective whilst the second one is projected on the surface under the examination. The beams become to interfere forming an interference pattern. CCD camera is used to detect the pattern. As the illumination comes from a broadband light source, the interference can be observed only when both of the optical paths are of the same length. By moving the objective's lenses along vertical axis and applying the patented coherence correlation algorithm the point where the maximum interference occurs can be found for each single pixel of the CCD matrix. In the result of tracking of the objective's lenses position during this process a three dimensional image of the surface can be created.

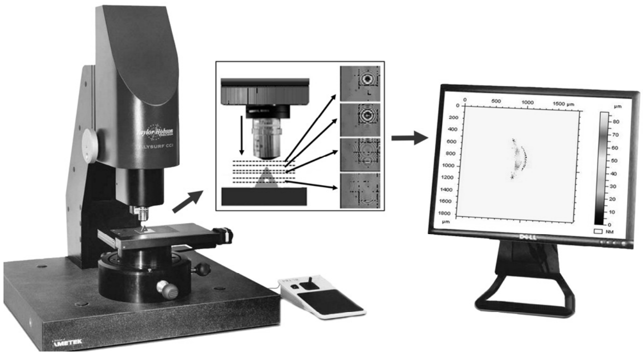

Fig. 3. Measurement of height distribution using Talysurf CCI 6000
Rys. 3. Pomiar rozkładu wysokości przy zastosowaniu Talysurf CCI 6000

The system uses a series of advanced computer algorithms to record the exact vertical position for each point on the surface with sub-nanometer resolution. It is important to note that the vertical resolution is independent of the magnification used, allowing the use of low magnifications to study wider area with high resolution.

4. Results and discussion

4.1. Measurement of tool geometry

Cutting geometry for PCBN tools is characterized by a large negative rake angle, a reinforced edge chamfer to avoid the chipping of the cutting edge due to the large compressive stresses, and an edge radius obtained by honing. Figure 4 presents the cutting tool geometry: rake face with chamfer, flank face with rounded cutting edge.

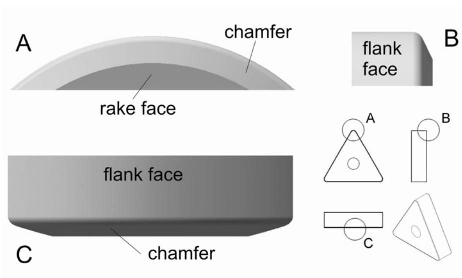

Fig. 4. Cutting tool geometry of tool nose embracing chamfered corner: A – front view of rake face, B – side view of flank face and chamfer, C – front view of flank face
Rys. 4. Geometria ostrza ze ścinem: A – widok powierzchni natarcia, B – widok boczny powierzchni przyłożenia ze ścinem, C – widok powierzchni przyłożenia

Under conditions of finish machining, the chip formation occurs on the chamfer face where the main cutting force is the thrust force. Figure 5 shows the measurements of the tool wedge done in such a way that the chamfer face is in focus. In that way, the chamfer geometry is easy to measure and present. Instrument depth of field limits the number of points possible to measure on flank face. Nonetheless, the measured points make possible the identification of honing radius and other characteristics both for CB20 and for 7020 cutting tools (Fig. 5).

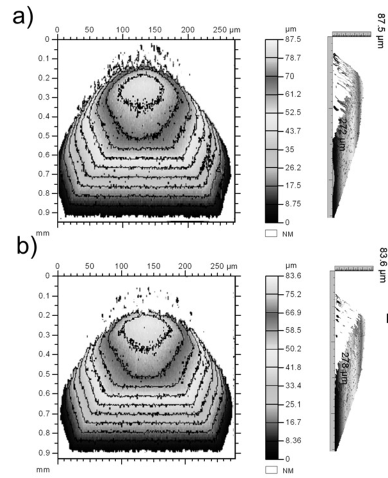

Fig. 5. Measurement of chamfered corner for tool material a) 7020 and b) CB20
Rys. 5. Pomiar geometrii dla materiału ostrza skrawającego a) 7020, b) CB20

4.2. Measurement of flank wear

At the early stage of cutting, initial breakdown in cutting edge with the edge rounding is observed with only a flank wear. At the beginning, the abrasive processes can be seen only in a region of edge rounding. When the tool is coated, high temperature and pressure make it to be turn out. Because of the size of CBN grains for PCBN tools and wearing process, the flank face is very developed.

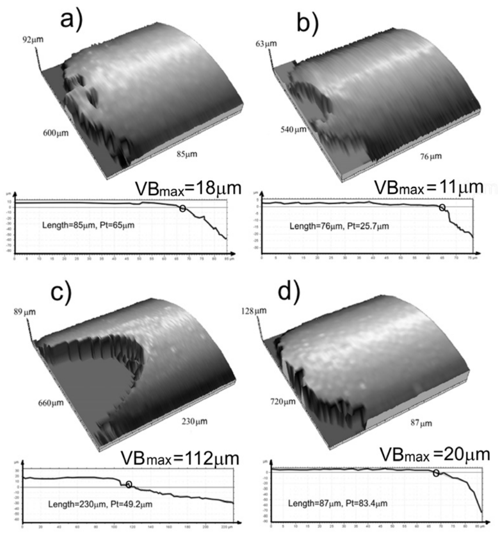

Fig. 6. Flank wear measured with Talysurf CCI 6000
Rys. 6. Zużycie powierzchni przyłożenia mierzone za pomocą Talysurf CCI 6000

Measurement of 7020 cutting tool in different state of wear was presented in Figure 6. Flank face in axonometric view shows smooth rounded surface. It is measured in such a way so that the cutting edge was fully outlined. The presented measurements are done in the same conditions but they are presented in different range of spatial parameters.

Curvature of the tool rounding makes possible the acquisition of only tiny part of the rounding. Number of points possible to measure was very limited. The transition between flank face and chamfer face is visible as the border of possible to measure points along the rounded cutting edge.

The wear area is difficult to measure hence the points of wear area are indicated as non-measured points or regions. The measurement of these points is completed by applying replacement of them with minimal value of all the measured points. Flank wear in this way is visible as the erosion of flank face in a neighbourhood of cutting edge. The averaged profile taken perpendicularly to the cutting edge indicates the location of points on flank face. Reduced height in relation to minimal shows the maximal value of wear.

The flank wear in finishing operations influences the machined surface even if it is very small. The tool flank wear character of 7020 PCBN tools shows the chipping of tens micrometers. Cutting of hard particles causes the abrasion of cutting edge and its roughness.

4.3. Roughness of the cutting edge rounding

Cutting edge – its roughness in both directions influences the machined surface. Change of edge radius influences the microcutting processes and the machined surface roughness along the cut traces. The irregularities along the cutting edge are mapped on the surface by direct scratching of the tool rounding. So the measurement of cutting edge roughness becomes the key factor in description of the whole cutting process.

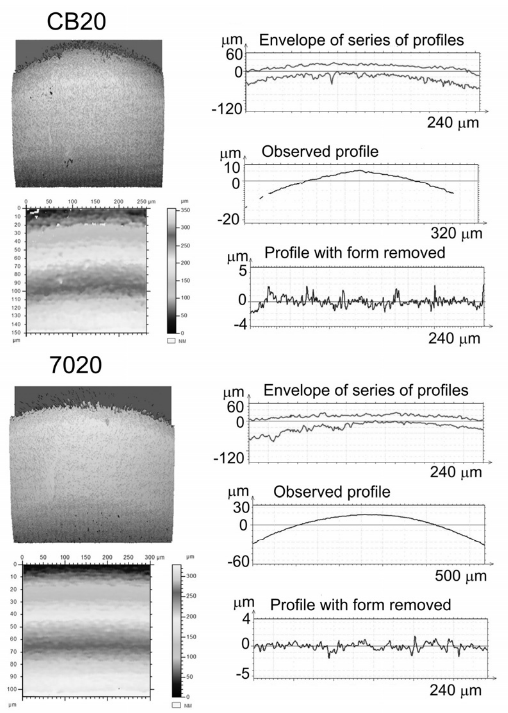

Fig. 7. Roughness of cutting edge for a) CB20 and for b) 7020 tool material
Rys. 7. Chropowatość krawędzi skrawającej dla a) CB20, b) 7020 materiału ostrza

Figure 7 shows the cutting edge from the view of chamfer face. Series of profiles are presented as the envelope inside which all the profiles are included. For CB20 cutting tool material the envelope is more symmetric than for 7020 cutting tool material. Measurements of averaged roughness parameters of the cutting edge are difficult to evaluate with CCI 6000 because of the difficulties with obtaining sufficiently long sampling length. However, the maximal roughness parameters are possible to measure along the cutting edge. For CB20 they were slightly greater than for 7020 cutting tool material.

5. Conclusions

Analysis of traces of wearing for both wedges revealed certain common features. The wear land starts to develop from the point in which the cutting edge cuts through a deformed layer. Value of depth of cut determines the location of the beginnings of the wear land. The cutting takes place on the main cutting edge up to a certain point, which divides it into a part belonging to the main cutting edge – creating the chip – and an auxiliary cutting edge – constituting roughness of the machined surface. Cutting ends at this point as thickness of the cut surface is too thin to have chip removed. Machined surface is created behind the division point on the rounded tool nose.

Micro-geometry of the cutting edge is the sum of changes from micro-geometry of machined surface, the phenomena of internal and contact frictions, reversibility of resilient deformation and plastic deformation processes. The rounding radius' value changes along the cutting edge. Correct set-up of a cutting wedge in relation to the optical axis of CCI 6000 enabled the measurements of the parameters of tool geometry, flank wear and roughness of cutting edge.

The measurements of tool geometry enable the estimation of such parameters as tool nose radius, honing radius, angles and other geometric parameters. The parameters of tool wedge geometry influence the cutting process and their estimation is crucial for monitoring of machined surface quality.

Measurements of tool faces done perpendicularly to the instrument axis make possible the calculation of wear parameters such as depth of crater wear, shortening of the tool, flank wear width.

The problem occurred when measuring the roughness of cutting edge. Sampling length for averaged parameters was too short. Additionally the non-measured points and stitching procedure introduced grater uncertainty for measurement evaluation. Roughness of cutting edge for finishing processes was possible for estimation in the range of maximal parameters.

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otrzymano / received: 11.05.2010
przyjęto do druku / accepted: 02.07.2010 *artykuł recenzowany*