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TECHNICAL PAPER

Influence of the cutting edge micro-geometry of PCBN tools on the flank wear in orthogonal quenched and tempered turning M2 steel

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Abstract Quenched and tempered high-speed steels obtained by powder metallurgy are commonly used in automotive components, such as valve seats of combustion engines. In order to machine these components, tools with high wear resistance and appropriate cutting edge geometry are required. This work aims to investigate the influence of the edge preparation of polycrystalline cubic boron nitride (PCBN) tools on the wear behavior in the orthogonal longitudinal turning of quenched and tempered M2 high-speed steels obtained by powder metallurgy. For this research, PCBN tools with high and low-CBN content have been used. Two different cutting edge geometries with a honed radius were tested: with a ground land (S shape) and without it (E shape). Also, the cutting speed was varied from 100 to 220 m/min. A rigid CNC lathe was used. The results showed that the high-CBN, E-shaped tool presented the longest life for a cutting speed of 100 m/min. High-CBN tools with a ground land and honed edge radius (S shaped) showed edge damage and lower values of the tool's life. Low-CBN, S-shaped tools showed similar results, but with an inferior performance when compared with tools with high CBN content in both forms of edge preparation.

Keywords PCBN · Edge geometry · Ground land · Honed edge radius · High-speed steel obtained by powder metallurgy · Orthogonal longitudinal turning

List of symbols

a_p	Depth of cut (mm)
f	Feed rate (mm^{-1})
r_β	Honed edge radius (mm)
r_ε	Tool nose radius (mm)
VB_B	Average flank wear land width (mm)
v_c	Cutting speed (m/min)
W	Chamfer width (mm)
γ_β	Land angle (°)
CBN	Cubic boron nitride
E	Honed edge
EDS	Energy dispersive spectrometry
PCBN	Polycrystalline cubic boron nitride
S	Ground land and honed edge
SEM	Scanning electron microscope

1 Introduction

Components manufactured by powder metallurgy are employed in many industrial activities. The most distinct of all processes that compose the powder metallurgy technology is the sintering step. This resulted in a spread of the

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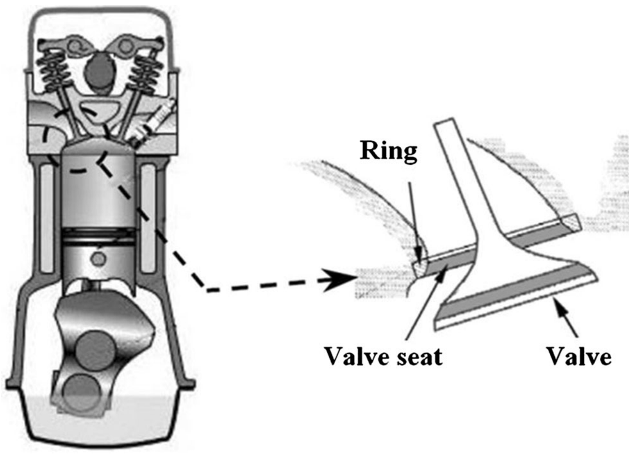


Fig. 1 Schematic diagram of an internal combustion engine showing the valve seat (adapted from Jesus [12]

term "sintered" to convey the manufacturing of any component obtained through a powder metallurgy technique. A common example of a sintered component is the valve seat of internal combustion engines (Fig. 1). One essential requirement for the valve seats is the high wear resistance in high temperatures, aggressive chemical environment and high mechanical stress loads. The rings for these valve seats are commonly manufactured with high-speed steels by metallurgy, then quenched and tempered. In order to meet the dimensional specifications, they go through a finishing machining step [29].

In order to machine these rings, polycrystalline cubic boron nitride (PCBN) tools are employed due to their mechanical properties, chemical stability and thermal shock resistance. These tools might present coating, chip breakers and customized geometries when demanded by specific applications.

The control over customized cutting geometries is still slightly dominated by tool manufacturers and only recently has been offered in the suppliers' portfolios. The influence of the tool edge geometry over the machining of sintered, quenched and tempered high-speed steels is not described in the literature.

The main objective of this work is to investigate the influence of the honed edge PCBN tools, with and without a ground land in orthogonal longitudinal turning of quenched and tempered M2 high-speed steels, in terms of the wear behavior.

1.1 PCBN tools

PCBN tools are composed of cubic boron nitrite (CBN) grains in a binder matrix (metal or ceramic) chosen according to the CBN load. Tools with a high CBN content, ranging from 80 to 95 % in weight of CBN, employ a metallic binder. Tools with a CBN content between 40 and 70 % of the tool's weight usually employ a ceramic binder [16, 19, 34]. PCBN tools are used in the turning of quenched and tempered ferrous materials, mainly for the finishing steps due to their high toughness and thermal stability as well as their lower chemical affinity for ferrous materials [28]. These tools are fragile with a high tendency for fractures. It is necessary that PCBN tools have their edges prepared in order to enable a good performance under these hostile conditions. According to Zareena et al. [36], the best results for the PCBN tools depend mostly on the tool's CBN content and binder material.

1.2 Low-CBN tools

Studies on the turning of hardened AISI 52100 by Narutaki and Yamane [22], Barry and Byrne [2] and Chou et al. [4], showed that low-CBN tools had lower wear rate values than tools with a higher CBN content. Bossom [3] mentions that the wear in low-CBN tools is due to its low thermal conductivity, which retains the heat in the cutting region. Chou et al. [4], when machining AISI 52100 with low-CBN tools, found the presence of grooves on the flank after a high cutting speed (240 m/min) process. The author concluded that adhesion was the mechanism most responsible for the wear, stating that tools containing lower contents of CBN have better resistance. Luo et al. [20] and Poulachon et al. [25] studied the tool wear on low-CBN tools when machining different quenched and tempered steels. Based on the wear grooves observed on the tools' flank, they concluded that the main mechanism for the CBN tools wear was related to the binder abrasion due to the carbide particles, causing the grains' pullout. Tool breakage in tools with a low-CBN content and ground land edges was verified by Mahfoudi et al. [21] when machining AISI 4140, 50 HRC, with $v_c = 400$ m/min, 0.10 mm feed and 1.0 mm cutting depth. Although in some studies the results showed tool breakage, Lahiff et al. [19] concluded that tools with low-CBN content presented a better performance during turning of hardened materials regarding tool life and surface finishing when compared with tools with a higher load of CBN.

1.3 High-CBN tools

High-CBN tools usually comprised metallic binders such as Co, Al and W. They have higher thermal conductivity, therefore better at dissipating the heat, lowering the temperature in the cutting region [9]. Regarding this difference on thermal conductivity, Bossom [3] concluded that this was the reason for the lower performance of high-CBN tools during the finishing steps of the turning of hardened materials. Through the study of the flank wear marks on high-CBN tools after turning a hardened and tempered AISI 52100 (61–63 HRC), with the aid of SEM, Chou et al. [4] concluded that the layers adhered to the tools were tightly bound and that adhesion was the dominant wear mechanism. This type of adhesion in high-CBN tools was also observed by Arsecularatne et al. [1] when machining AISI D2. Regarding the chipping in PCBN tools, the results encountered by Hodgson et al. [8], when machining AISI M2 obtained by conventional metallurgy, showed an unsatisfactory performance of the tool due to premature failure of the tool's cutting edge. The experiments were performed on tools with ground land edges and with cutting speeds ranging from 80 to 120 m/min for a 0.05 mm/rev feed.

1.4 Edge geometry of PCBN tools

The edge comprises the geometric region where the tool's rake face and flank meet. The edge's radius defines the sharpness of the tool and it is the region responsible for the actual cutting of the material. Depending on their use, PCBN tools might require further modifications on the edge geometry in addition to the grinding of the face and flank to achieve good results. The modification on the edge shape consists of producing a land and/or a radius on the edge through honing, therefore protecting it from chipping, improving its impact resistance and increasing the tool life [13]. Due to these geometric changes, the heat transfer area from the cutting zone to the cutting edge region increases [19].

Several alternatives for the edge preparation are described in the literature. According to Karpat and Özel [13] the alternatives are: single land (Fig. 2a), double land (Fig. 2b), land with a small honed radius (S shape) (Fig. 2c), just a honed radius (E shape) (Fig. 2d), honed in parabolic horn shape (Fig. 2e), honed in cascade shape (Fig. 2f) and honed with variable radius (Fig. 2g). These features intend to serve specific applications. The land on the tool's rake face is ground with an inclination between 15° and 20° and a width between 0.10 and 0.20 mm. The symmetrically honed edge radius is obtained through brushing [26] or micro-abrasive jet machining [35]. Tools with a ground land and a honed edge radius are obtained by combining the two previous processes with a small radius between the flank and the rake angle on the land. Parabolic radius honing consists of rounding the edge on the flank face either in a waterfall shape (the edge radius increases closer to the flank) or a trumpet shape (the edge radius decreases closer to the flank). Tools with variable edge radii present radii with a decreasing value on the direction of the nose radius of the tool. Regarding the types of edges, Wyen [35] compared honed edge tools with waterfall and trumpet shape profiles, concluding that the waterfall profile results in higher loads on the tool flank, while a trumpet profile tends to decrease the forces on the flank. For the author, these asymmetrically honed edge tools present similarities with the tools with too small or too large honed edges. Tools with trumpet shape profile also presented longer tool life than tools with a waterfall shape profile.

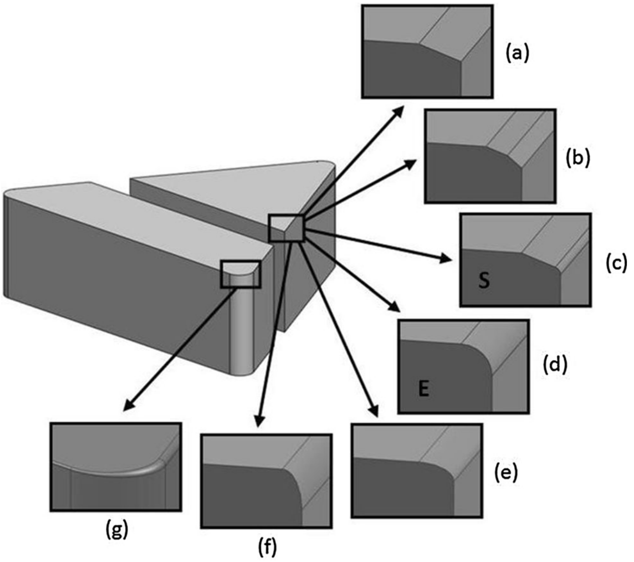


Fig. 2 Edge preparations **a** ground land, **b** double land, **c** ground land with honed edge radius, **d** honed edge radius, **e** trumpet shape, **f** waterfall shape, **g** honed with variable edge radius

Research reveals that ground land edges might have an influence on the compressive residual stresses during the machining of quenched and tempered materials, as an increase on the chamfer angle causes an increase on these loads [8, 18, 33]. This increase in the chamfer angle promotes the residual compressive stress under the surface, but/and provokes a temperature increase on the tool. In addition to the influence on the compressive residual stresses, the chamfer also influences the machining force.

Tools with honed edges have greater surface contact with workpiece and chip, increasing the heat transfer from the cutting zone to the tool and improving the surface roughness and integrity on the machined workpiece [19]. The purpose of rounding the tool's edge is to protect the cutting edge from chipping, to improve its impact resistance and to increase the surface area for the heat transfer from the cutting zone [6, 13].

According to Lahiff et al. [19] and Dogra et al. [6], the turning of quenched and tempered ferrous materials with the undeformed chip thickness and tool's edge radius in the same magnitude order, requires tools that can withstand high mechanical and thermal stresses. For these situations the edges should be prepared accordingly, since the process can result in high tensile residual stresses on the workpiece's surface and also cause sub-surface damage [6, 15, 23]. For fragile tool materials, ground lands and honed edges are used to increase the tool's life by protecting it against chipping and breakage and increasing its resistance to mechanical and thermal stresses.

1.5 PCBN tool wear mechanisms

PCBN tools are influenced by wear mechanisms such as abrasion [24], adhesion [7, 17], diffusion [17], chemical wear [2, 7, 9, 20], adhesion pullout and entrainment in the direction of the cutting speed and chip flow [14, 19, 31, 32]. These wear mechanisms contribute greatly to the flank wear which is the main criterion for determining the tool's end of life. The flank wear reduces the clearance angle to zero causing an increase in the contact area between the tool flank and the cutting surface, therefore resulting in greater friction and heating in the contact zone. With the increase of the cutting speed, the temperature increases at the interface between the tool and the flank. The cut surface becomes more pronounced [20]. Another type of PCBN tool wear is the crater, which is generally associated with high temperatures and high pressures on the tool–chip interface and decreases the abrasion resistance with the appearance of weaker composites. These composites are generated by the chemical affinity between the different materials in the work area and, being less resistant, are removed by the chip flow on the tool's surface [10, 20, 27].

1.6 Orthogonal longitudinal turning

The orthogonal longitudinal turning is defined as a machining process with a single-edge cutting tool where the edge is perpendicular to the cutting and feed directions. When orthogonal turning is performed on the machining of a cylinder, there is no influence of the tool's nose radius on the process and the cutting surface coincides with the machined surface. This process is capable of achieving a surface integrity comparable to those found in ground components [11].

Turning can be classified as hard turning when machining workpieces have hardness values between 58 and 65 HRC. Some requirements for a successful longitudinal orthogonal turning of quenched and tempered steels are the use of highly precise and rigid machine tools, very hard and resistant tool materials, tool geometry with a negative rake angle and large wedge angle, resistant wedge geometry with appropriate ground land and/or radius, a rigid tool holder and appropriate cutting conditions [16]. PCBN tools can be used to turn quenched and tempered steels either in the form of interchangeable tools with a brazed CBN corner on a carbide substrate or fully in CBN.

2 Methodology

In order to analyze the influence of the edge geometry on PCBN tools on its wear resistance when machining quenched and tempered sintered high-speed steels, experiments were performed on a horizontal CNC Romi Galaxy lathe with high rigidity. Each test was performed only once due to the high costs (tools, workpieces, machining). The M2 high-speed steel rings used in the experiments, obtained by powder metallurgy, presented an external diameter of 28.7 mm, a 2.2-mm-thick wall and a 9.5 mm length with their apparent hardness between 350 and 450 HB (Fig. 3).

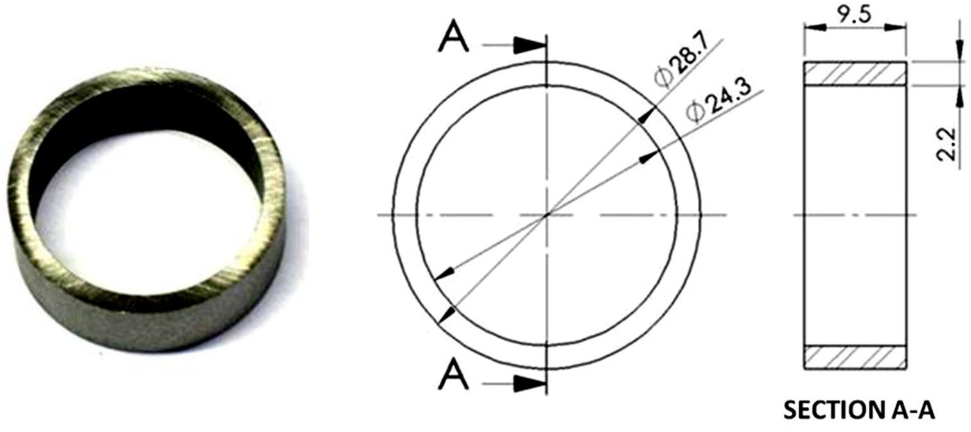


Fig. 3 Ring-shaped workpiece and dimensions

Table 1 Chemical composition (% weight), density and hardness of sintered M2 high-speed steel

C	Co	Mo	Cr	S	Other	Fe	Density (g/cm^3)	Apparent hardness (HB)
0.7–1.1	5.5–6.5	6.0–7.0	3.5–4.5	1.0–1.4	2	Balance	6.8	350–450

The term apparent hardness is used given the lesser resistance encountered by the indenter in parts produced by powder metallurgy. This lower resistance is due to the presence of pores natural to the sintering process. Thus, the lower values of hardness in parts produced by powder metallurgy do not mean necessarily that the functional properties of the material are also affected negatively.

Table 1 shows the chemical composition and the physical and mechanical properties of the rings.

The ISO TNMG110308-LF tools are produced with a PCBN layer with an average grain size about 2 µm on a tungsten carbide substrate. Both low-CBN (CBN10) and high-CBN (CBN200) tools were employed in the experiments. In both classes, tools with a honed edge radius were employed—with a land ground (S shape) and without it (E shape). The CBN layer properties are shown in Table 2.

The S-shaped cutting edge has a 0.10-mm-wide land with an angle of 20°. According to the manufacturer, the honed edge radii (r_β) are approximately 0.015 and 0.025 mm for the S-shaped (Fig. 4a) and E-shaped (Fig. 4b) edges, respectively. The chosen limit value for the flank wear $VB_B = 0.10$ mm was established during early chipping tests.

The selected cutting speed values were based on the experiments performed by König and Neises [17], Luo et al. [20], Poulachon et al. [24], Kurt and Seker [18], Diniz et al. [5], Klocke and Kratz [15], Karpat and Özel [13] and Özel [23]. For the experiments, cutting speeds between 100 and 220 m/min were employed. The feed value was based on the works of Zhou et al. [37], Karpat and Özel [13] and Katuku et al. [14] and maintained constant with $f = 0.05\ \text{mm}^{-1}$. The machining width of 2.2 mm was established considering the wall thickness of the workpiece. The input variables of the experiments are shown in Table 3.

Table 2 Material properties of the PCBN tools [30]

Grade	Binder	Knoop hardness (GPa)	Grain size (µm)	Thermal conductivity (W/mK)	CBN (vol.%)
CBN10	TiN	27.5	~2	44	50
CBN200	Co–W–Al	28.4	~2	94	85

In the orthogonal longitudinal turning process, the cutting geometry of the tool is reproduced on the cutting surface, which coincides with the machined surface of the last revolution of the probe during the cutting procedure Fig. 5a. In longitudinal turning, the cutting surface is continuously removed and the machined surface reproduces only a small parcel of edge in the range of the corner radius region, Fig. 5b.

Each workpiece, 9.5 mm in length, allowed 13 turning experiments with 0.4 mm feed displacement each in order to simulate a typical industrial application. From the ring length, 3.8 mm was used to fixate the ring in the jaws and 0.5 mm was cleared for safety against collisions between the tool and the jaws. Figure 6 shows the workpiece fixed on the chuck (a), the cutting strategy with the divisions representing the feed displacements (b) and place measurement of flank wear (c). The flank wear width of $VB_B = 0.10$ mm and the chipping of the edge were adopted as criteria for the end of tool life, prevailing which one occurred first.

Figure 7 shows the first and last cut on each workpiece.

In order to measure the flank wear the tool was removed from de tool holder after 260 cuts (20 parts machined). The tool was thoroughly cleaned and fixed on a Zeiss Stemi SV6 stereoscope for the evaluation. The

Table 3 Input variables for the experiments

Grade PCBN	Cutting edge geometry	Feed, f (mm^{-1})	Depth of cut, a_p (mm)	Cutting speed, v_c (m/min)
CBN10	S (ground land and honed radius)	0.05	2.2	100–140–180–220
	E (only honed radius)			
CBN200	S (ground land and honed radius)			
	E (only honed radius)			

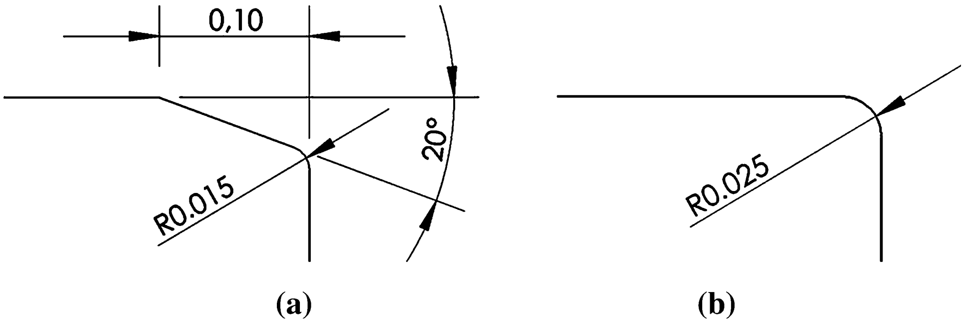
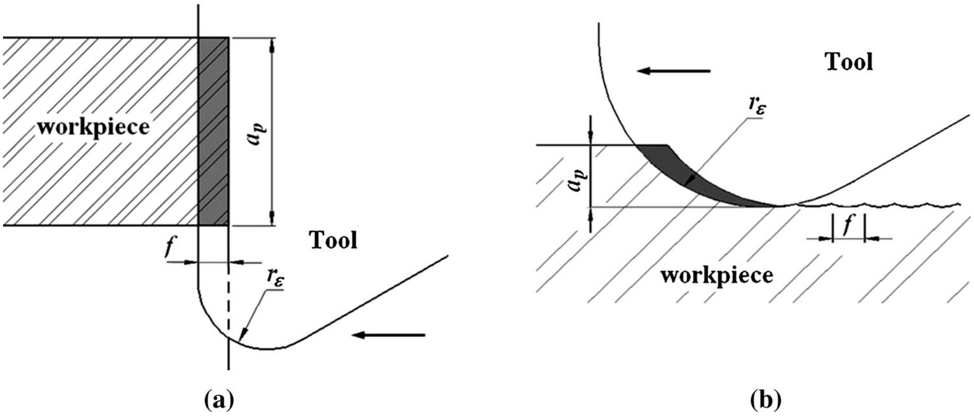


Fig. 4 Dimensions of the edge geometry on the PCBN tools: **a** geometry S and **b** geometry E (units in mm)

Fig. 5 Cutting region in orthogonal longitudinal turning (**a**) and longitudinal turning (**b**)



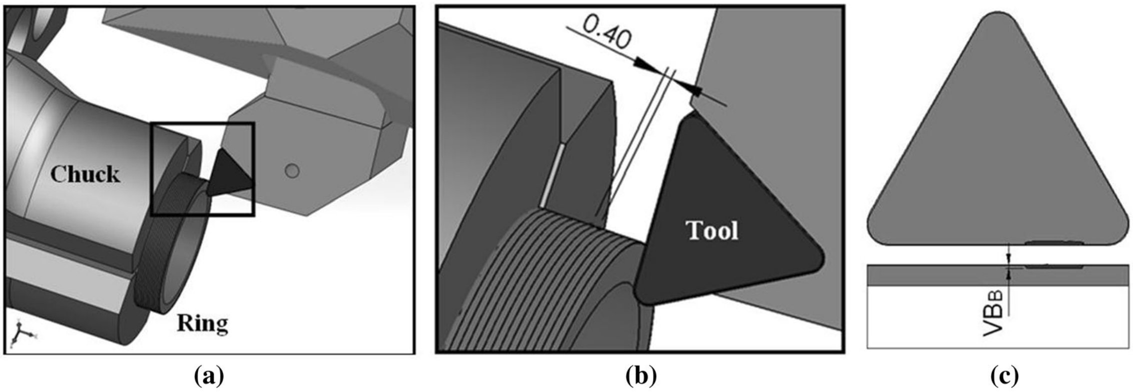
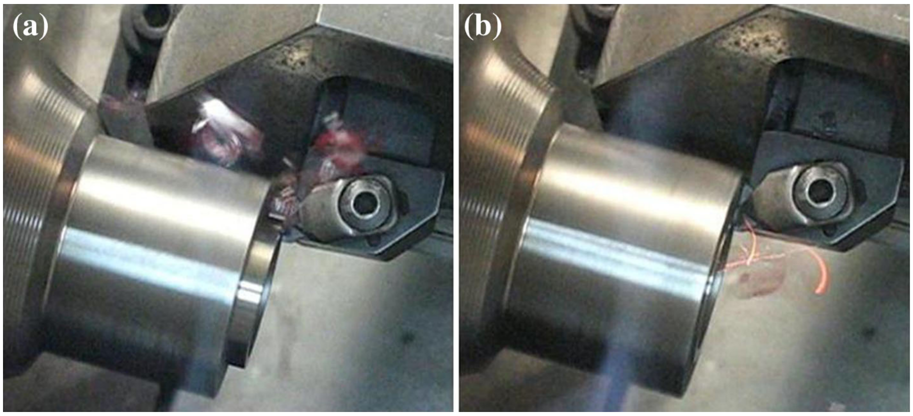


Fig. 6 Schematic representation of the orthogonal turning (**a**), the 13 cuts 0.4 mm apart (**b**) and the place flank wear measurement (**c**)

Fig. 7 **a** 1st cut and **b** 13th cut



digital images were stored in a computer. The tool wear measurement was performed with a CAD software (AutoCAD$^{®}$ 2009). The measured wear values were stored electronically. Whenever the specified flank wear was found, the experiment was ended. Figure 8 shows an example of the flank wear measurement performed with the CAD software.

At the end of each machining experiment, PCBN tools images were obtained on a Zeiss EVO LS15 and a Hitachi TM3000 SEM energy dispersive spectroscopy equipment.

3 Results and discussion

The discussion of the machining results is based on the comparison of the wear progress between different combinations of the input variables.

3.1 Influence of the cutting speed on the flank wear for S-shaped and E-shaped PCBN tools with high CBN content

The behaviors of the flank wear for both the S-shaped and E-shaped PCBN tools with high CBN content when machining M2 high-speed steel are shown in Fig. 9a, b, respectively. It is possible to observe that with S-shaped high-CBN PCBN tools (CBN200S) the chipping of the edge preceded the specified flank wear limit on all experiments, causing their interruption.

All the E-shaped tools (CBN200E) reached the stipulated flank wear. The highest number of cuts was obtained with a 100 m/min cutting speed, as shown in Fig. 9b. It can be seen on Fig. 9b that the flank wear is basically the same for every cutting speed for the first 1,560 cuts (or 120 workpieces) approximately. Further cuts presented higher wear in processes with a higher cutting speed.

Figure 10 shows the damage on the rake faces of S-shaped high-CBN PCBN tools that occurred before reaching the VB criterion. The macro- and micro-chipping is caused by the high tensile stresses in the edge and land region, which presents an effective rake angle of −26° that increase with the flank wear progression. This damage behavior was also mentioned by Karpat and Özel [13].

The results differed from the works of Zhou et al. [37], Kurt and Seker [18] and Karpat and Özel [13], who affirmed that the land helped preventing the occurrence of chipping, and from the work of Klocke and Kratz [15], who stated the purpose of the land was to protect the edge from chipping.

The observed behavior confirms the results obtained by Hodgson et al. [8] for the machining of high-speed steels

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Fig. 8 Flank wear measured on a digital image with the aid of a CAD software (amplification for the flank wear measure = ×20)

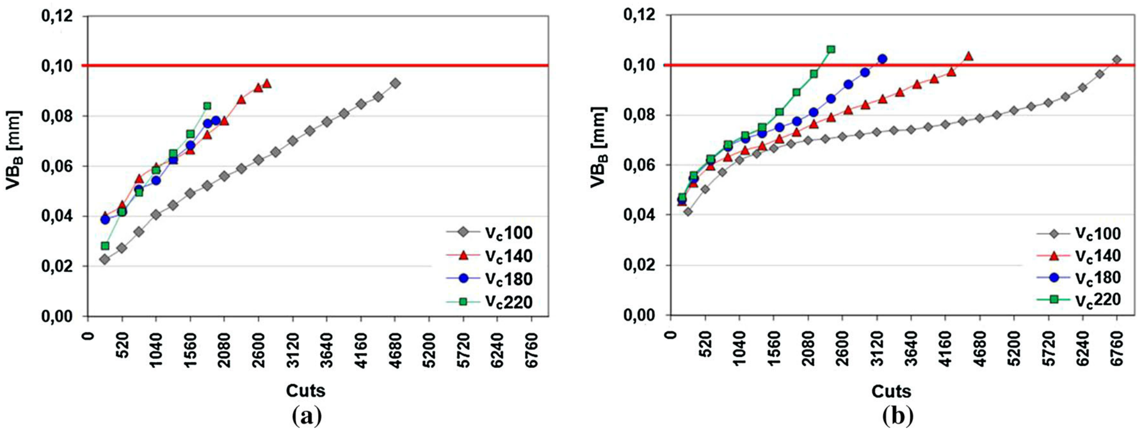


Fig. 9 Flank wear for PCBN tools with high CBN content (CBN200), with S-shaped (**a**) and E-shaped (**b**) geometries

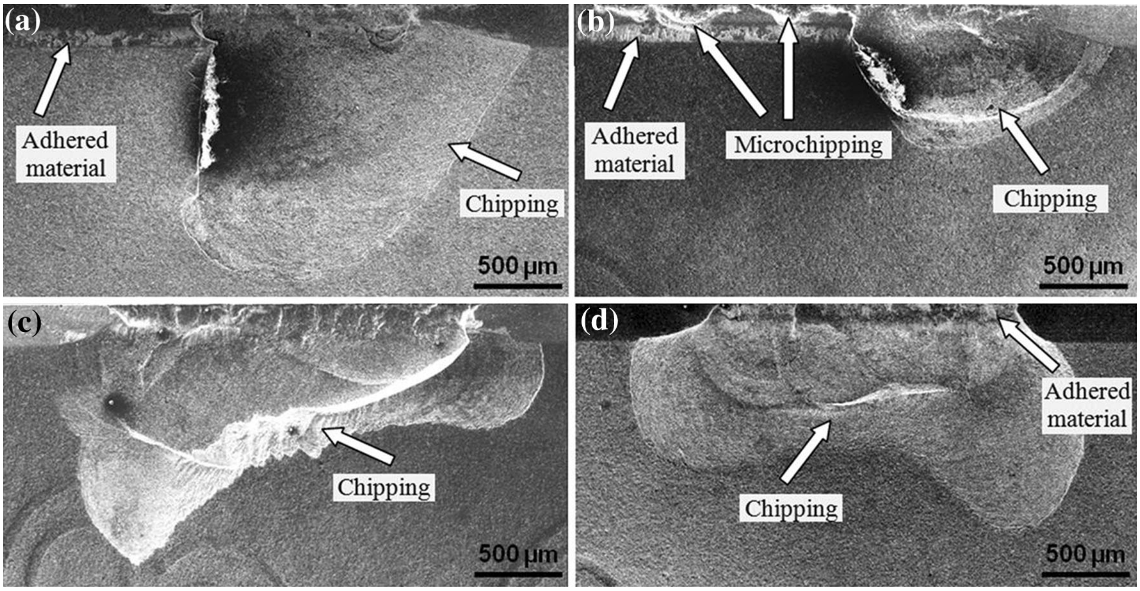


Fig. 10 Tool rake face damage for S-shaped tools with high CBN content

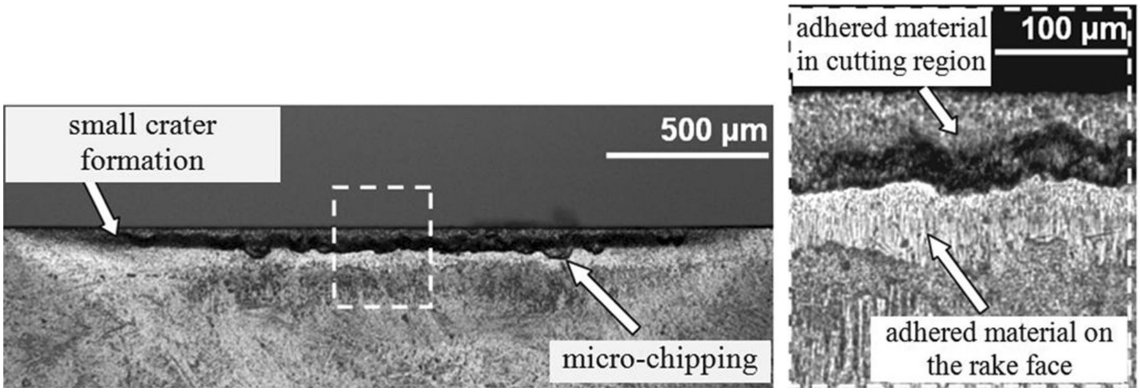


Fig. 11 PCBN tool rake face of an E-shaped high-CBN content tool (CBN200E) at the end of the tool life when machining with $v_c = 180$ m/min

manufactured by conventional processes, where CBN tools with a land presented shorter tool life than tools without it.

Figure 11 shows the rake face of a high-CBN content tool with a honed edge radius (E shape). The presence of micro-chipping and adhered material in the contact region can be observed. The adhered material on the flank of the tool presented the chemical elements of the machined workpiece when analyzed by EDS. During the interruption by the feed reversion, the machining thickness decreases from its maximum value to zero. Therefore, the cutting conditions are strongly influenced by the reversion procedure. When machining thickness approaches zero, the chipping stops and a strong crushing occurs both at the flank–cutting surface interface, as well as between the tool rake face land and the inferior surface of the chip. Throughout this phase, it is common for the high compressive stresses and lack of chip flow to cause greater adhesion on the tool's rake face and flank, masking the wear mechanisms. These adhesions can be mistakenly interpreted as the common mechanism found on the usual cutting speed range.

Adhesions on the flank wear region were found on all experiments for both edge geometries (Fig. 12).

Figure 13 shows the EDS analysis of the region marked in Fig. 12h, machined with a cutting speed of 220 m/min. The analysis identified the presence of chemical elements Fe, C, Co, V, Cr and W that do not appear on the composition of the PCBN matrix.

The wear behavior of CBN200E tools when machining sintered M2 high-speed steel showed that this edge geometry enables more cuts than the S-shaped tools before the end of life.

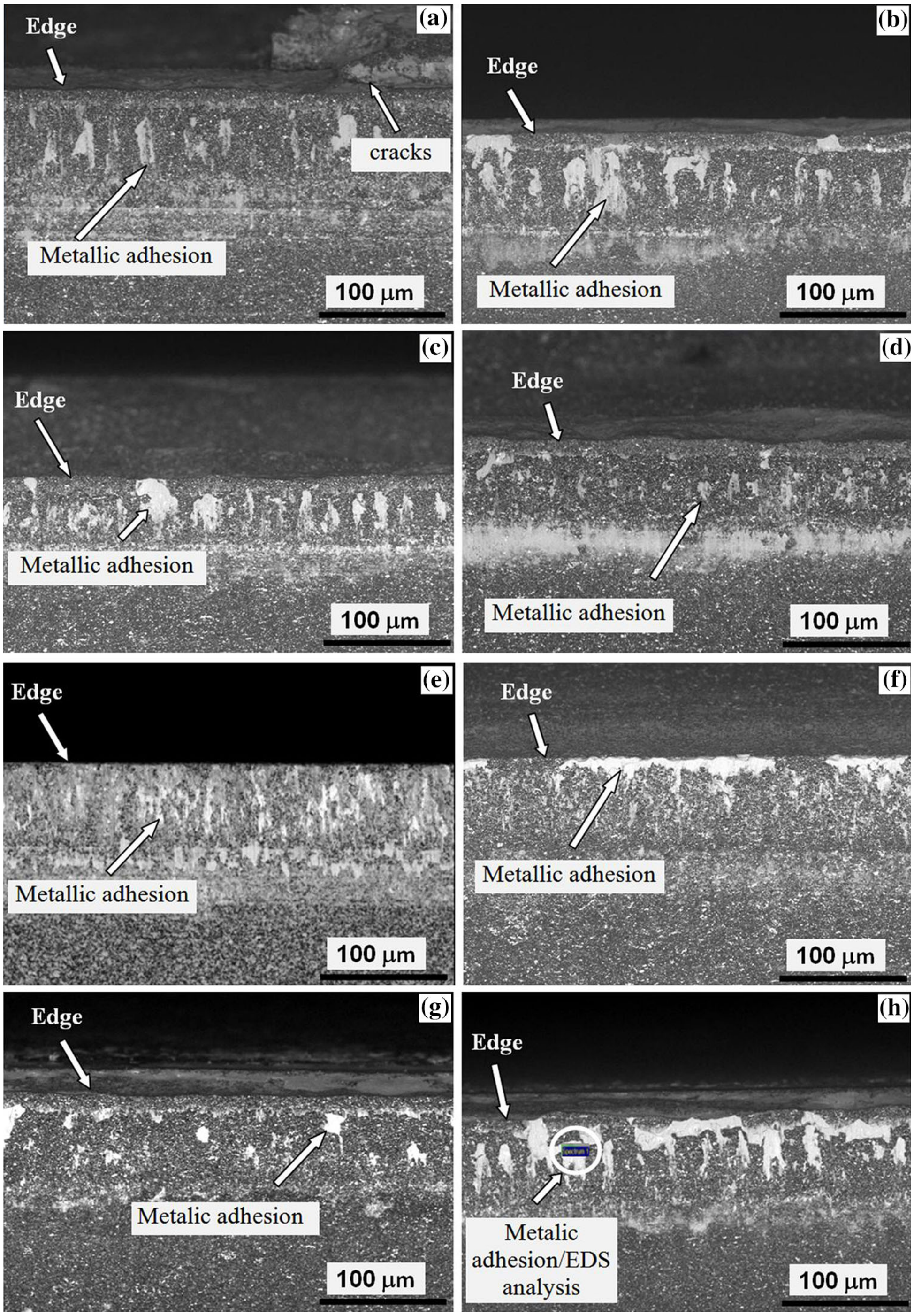


Fig. 12 Flank wear marks on CBN200S and CBN200E tools at the end of tool life for cutting speeds from 100 to 220 m/min

3.2 Influence of the cutting speed on the flank wear for S-shaped and E-shaped low-CBN PCBN tools

Figure 14a, b shows the flank wear behavior for both S-shaped and E-shaped low-CBN PCBN tools, respectively. Although the results present similar values, it is difficult to evaluate the level of similarity given the lack of further experiments.

Figure 15 shows the flank wear marks at the end of tool life for the PCBN tools with low-CBN content and both geometries, where abrasive wear and metallic adhesions were observed, but no cracks or chipping of the edge region were found. The EDS analysis shows that the adhesion on the flank wear marks originated from the workpiece.

In relation to honed edge tools (E shape), Lahiff et al. [19] and Dogra et al. [6] report that these tools have greater

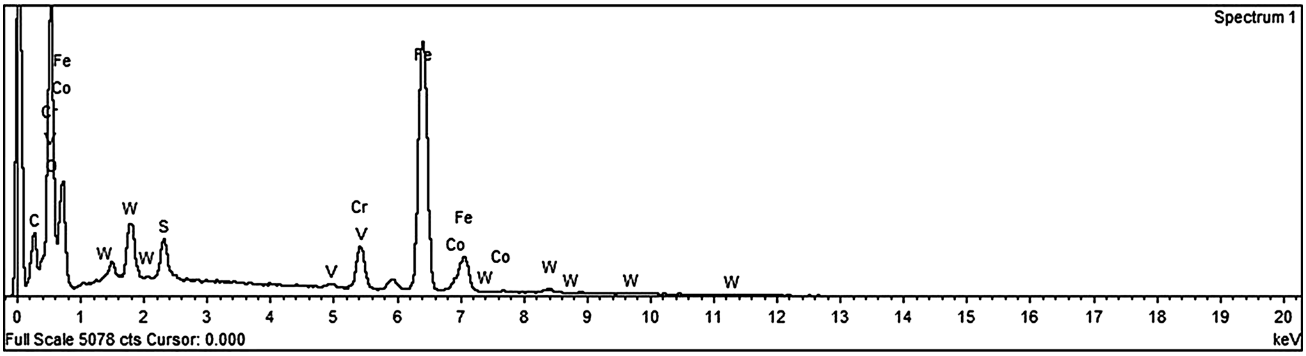
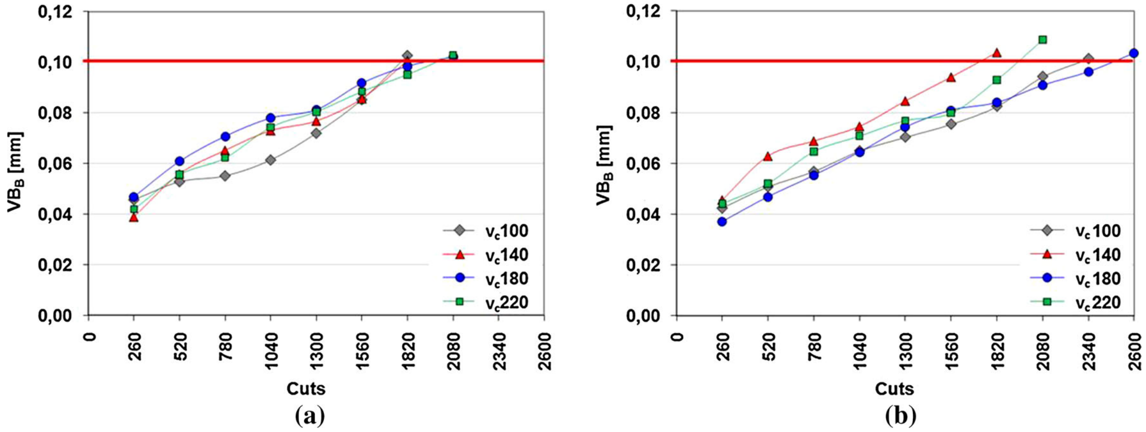


Fig. 13 EDS analysis performed on the metallic adhesion on the flank of a CBN200E tool after machining a workpiece at $v_c = 220$ m/min (end of tool life)



(a) (b)

Fig. 14 Flank wear for PCBN tools with low-CBN content (CBN010), with S-shape (**a**) and E-shape (**b**) geometries

surface contact with the workpiece and chip, increasing the heat transfer from the cutting area to the tool, showing improvement in surface finish and in surface integrity of the machined part. Karpat and Özel [13] and Dogra et al. [6] complement that the purpose of the use of honed edge tools (E shape) is also to protect the edge from chipping, improving its impact resistance.

A hypothesis for the shorter life of the low-CBN content tools—for both ground land and honed geometries (S shape) and only honed (E shape)—was the lower hardness and also the low thermal conductivity of the tool (low-CBN content tools have 44 W/mK while high-CBN content tools, 94 W/mK; Table 2). This low thermal conductivity let a greater quantity of heat to be retained in the cutting region, increasing tool wear; a hypothesis also cited by Bossom [3]. For chipping that occurred in high-CBN content tools (CBN200S) and not in low-CBN content tools (CBN10S), the reason given was the higher hardness of the tool provided by most volume of CBN grain in its composition (Table 2), which makes it more susceptible to chipping.

The crater wear was not significant in any of the tools employed and was never a reason for the end of tool's life.

4 Conclusions

The analyses of the experimental results with PCBN tools presenting different CBN compositions and edge geometries enabled the following ascertainments:

1. The E-shaped (only with honed edge) high-CBN PCBN tool (CBN200E) presented the longest tool life in terms of machined parts or cutting steps for the cutting speed range from 100 to 220 m/min. This behavior is related to the greater hardness and better heat dissipation given by the higher CBN content.
2. The adhesions found on both edge geometries and both PCBN classes throughout the range of cutting speeds had their origin in the workpiece.
3. The formation of crater wear on the PCBN tools with high CBN content for both edge geometries could be

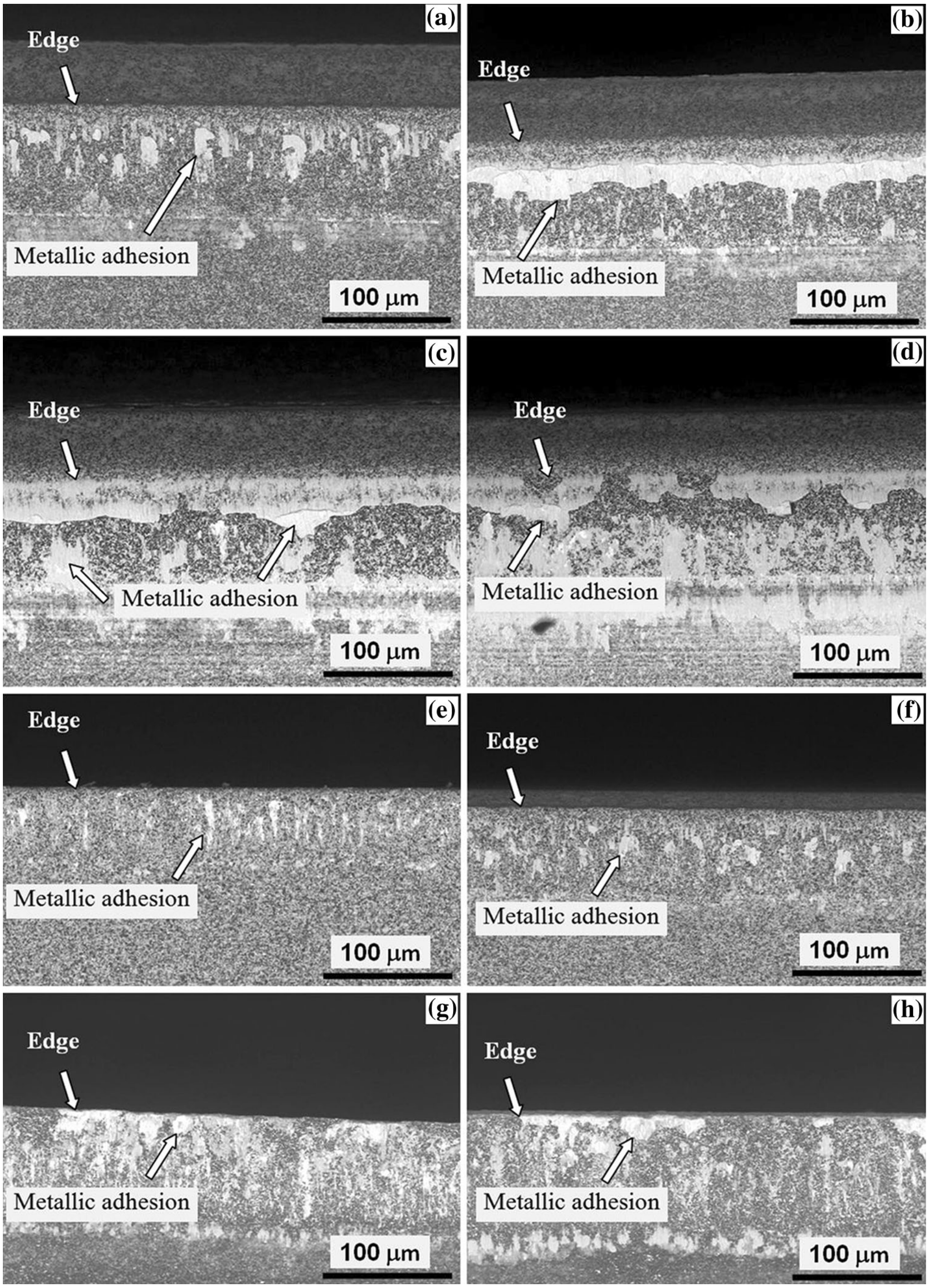


Fig. 15 Flank wear marks on CBN10S and CBN10E tools at the end of tool life for cutting speeds from 100 to 220 m/min

observed. However, this wear was not significant and did not determine the end of the tool life.

4. The tools with ground land and honed edge radius (S shape) and high CBN content showed chipping in the rake face for all cutting speeds. The damage was influenced by the negative geometry of the land and, therefore, by the higher shear and compressive stresses on the surface.
5. For the tool with low-CBN content, ground land and honed edge radius (S shape), the tool life increased with the cutting speed for the selected range.

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References

1. Arsecularatne JA, Zhang LC, Montross C, Mathew P (2006) On machining of AISI-D2 steel with PCBN tools. J Mater Process Technol 171:244–252

2. Barry J, Byrne G (2001) Cutting tool wear in the machining of hardened steels Part II: cubic boron nitride cutting tool wear. Wear 247:152–160
3. Bossom PK (1990) Finish machining of hard ferrous workpieces. Ind Diam Rev 5:228–232
4. Chou YK, Evans CJ, Barash MM (2002) Experimental investigation on CBN turning of hardened AISI 52100 steel. J Mater Process Technol 124:274–283
5. Diniz AE, Gomes DM, Braghini A Jr (2005) Turning of hardened steel with interrupted and semi-interrupted cutting. J Mater Process Technol 159:240–248
6. Dogra M, Sharma VS, Sachdeva A, Suri NM, Dureja JS (2010) Tool wear, chip formation and workpiece surface issues in CBN hard turning: a review. Int J Precis Eng Manuf 11(2):341–358
7. Farhat ZN (2003) Wear mechanism of CBN cutting tool during high-speed machining of mold steel. Mater Sci Eng A361:100–110
8. Hodgson T, Trendler PHH, Micheletti GF (1981) Turning hardened tool steels with cubic boron nitride inserts. CIRP Ann 30:63–66
9. Hooper RM, Shakib JI, Parry A, Brookes CA (1989) Mechanical properties, microstructure and wear of DBC50. Ind Diam Rev 89(533):170–173
10. Huang Y, Liang SY (2005) Effect of cutting conditions on tool performance in CBN hard turning. J Manuf Process 7(1):10–16
11. Huddle D (2002) A new direction for turning: plunge turning can be a cost-effective grinding alternative. Manuf Eng 128(4):76–82
12. Jesus ESJ (2006) Obtention, machining and wear of sintered alloys for automotive applications (in Portuguese). MSc thesis, Institute of Energetic and Nuclear Research, São Paulo-SP, Brazil
13. Karpat Y, Özel T (2007) 3-D FEA of hard turning: investigation of PCBN cutting tool micro-geometry effects. Transactions of NAMRI/SME, vol 35, 8 pp
14. Katuku K, Koursaris A, Sigalas I (2010) Wear mechanisms of PcBN cutting tools when dry turning ASTM grade 2 austempered ductile iron under finishing conditions. Wear 268:294–301
15. Klocke F, Kratz H (2005) Advanced tool edge geometry for high precision hard turning. CIRP Ann 54(1):47–50
16. König W, Komanduri R, Tönshoff HK, Ackerschott G (1984) Machining of hard materials. CIRP Ann 32(2):417–427
17. König W, Neises A (1993) Wear mechanisms of ultrahard, non-metallic cutting materials. Wear 162–164:12–21
18. Kurt A, Seker U (2005) The effect of chamfer angle of polycrystalline cubic boron nitride cutting tool on the cutting forces and the tool stresses in finish hard turning of AISI 52100 steel. Mater Des 26:351–356
19. Lahiff C, Gordon S, Phelan P (2007) PCBN tool wear modes and mechanisms in finish hard turning. Robotics Comput Integr Manuf 23:638–644
20. Luo SY, Liao YS, Tsai YY (1999) Wear characteristics in turning high hardness alloy steel by ceramic and CBN tools. J Mater Process Technol 88:114–121
21. Mahfoudi F, List G, Molinari A, Moufki A, Boulanouar L (2008) High speed turning for hard material with PCBN. Int J Mach Mach Mater 3:62–79
22. Narutaki N, Yamane Y (1979) Tool wear and cutting temperature of CBN tools in machining of hardened steels. Ann CIRP 28:23–28
23. Özel T (2009) Computational modeling of 3D turning: influence of edge micro-geometry on forces, stresses, friction and tool wear in PCBN tooling. J Mater Process Technol 209:5167–5177
24. Poulachon G, Moisan A, Jawahir IS (2001) Tool wear mechanisms in hard turning with PCBN tools. Wear 250:576–586
25. Poulachon G, Bandyopachyay BP, Jawahir IS, Pheulpin S, Seguin E (2004) Wear behavior of CBN tools while turning various hardened steels. Wear 256:302–310
26. Rech J (2005) Cutting edge preparation and surface issues, HSS Forum's international conference, Aachen
27. Rocha CA, Sales WF, Barcellos CS, Abrão AM (2004) Evaluation of the wear mechanisms and surface parameters when machining internal combustion engine valve seats using PCBN tools. J Mater Process Technol 145:397–406
28. Sahin Y (2009) Comparison of tool life between ceramic and cubic boron nitride (CBN) cutting tools when machining hardened steels. J Mater Process Technol 209:3478–3489
29. Salgado L, Ambrozio Filho F, Leal Neto RM, Colosio MA, Herrmann Filho CR, Rossi JL (2001) P/M high-speed steels for valve seat inset application. J Mater Manuf 110:261–264
30. Tools Seco (2005) Secomax PCBN: technical guide 2006. Grafiska Byran Örebro/PA Group Karistad—Fagersta, Sweden
31. Silva LR, Coelho RT, Catai RE (2004) Tool wear in turning with high speed cutting of the superalloy "waspaloy" (in Portuguese). Sch Mines Mag 57(2):109–114
32. Silva RHL (2010) Tool wear monitoring in end milling trough cutting power and acoustic emission and neural network (in Portuguese). MSc thesis, Federal University of Uberlândia-MG, Brazil
33. Thiele JD, Melkote SN (2000) Effect of cutting edge geometry and workpiece hardness on surface generation in the finish hard turning of AISI 52100 steel. ASME J Manuf Sci 122:467–479
34. Tönshoff HK, Arendt C, Ben AR (2000) Cutting of hardened steel. CIRP Ann 49:547–566
35. Wyen CF (2011) Rounded cutting edges and their influence in machining titanium, Dr-Ing. Dissertation, RWTH, Aachen
36. Zareena AR, Rahmanm M, Wong YS (2005) Binderless CBN tools, a breakthrough for machining titanium alloys. J Manuf Sci Eng 127:277–279
37. Zhou JM, Walter H, Andersson M, Stahl JE (2003) Effect of chamfer angle on wear of PCBN cutting tool. Int J Mach Tools Manuf 43:301–305