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Evaluation of the wear mechanisms and surface parameters when machining internal combustion engine valve seats using PCBN tools

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Abstract

This research aims to investigate the influence of cutting speed (v_c), depth of cut (doc) and feed rate (f) on the machining of valve seats of internal combustion engines using polycrystalline cubic boron nitride (PCBN) tools. The workpiece material was Fe–C–Cu–Ni–Mo alloy obtained from powder metallurgy technique. The quality of the resulting surface is fundamental for the performance of engines and was estimated by R_a, R_q, R_z, R_t and W_t surface roughness parameters, while relations between surface and cutting parameters were performed. Among the cutting parameters the cutting speed was the most influent on the wear of the tools. The predominant types of wear were flank and crater, while mechanisms as attrition prevailed at low v_c and diffusion at medium v_c. The dynamic instability identified by accelerometers at the machine was decisive in leading to discontinuous chip flow and chipping phenomena due to low fracture toughness of tool material.

Keywords: Polycrystalline cubic boron nitride; PM workpiece; Wear mechanisms; Combustion engines

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1. Introduction

Currently, the automobile market indicates that, in the next few years, the leading difference among industries will be cost and product commercialization, since in the areas of technology and quality of products there is a tendency for equivalence among manufacturers. Furthermore, there is an increasing need for better endurance and performance of automotive engines.

In new machining processes, all the factors involved, such as, simultaneous consequences on the environment, the workers health, the ease of conclusion of activities and the productivity are relevant when choosing the type of cutting tools available. Nowadays, there is a great variety of types of cutting tools available in the market. Each manufacturer suggests, according to the machining process, the most adequate cutting tools.

Nowadays, new technologies have been incorporated into the production lines, e.g. CAD/CAM, FMS, CBS and CIM systems. Among these processes, there are the numerical control machines, NC, CNC and DNC. The automation is increasingly more intense in tasks, mainly with the inclusion of robots for the execution of tasks which are more difficult, precise, repetitive or dangerous.

All these technologies have in common the automation aiming at the minimization of operation failure and the enhancement of the several stages of the production process [1,2]. For such new processes, a series of dimensional controls have been introduced such as statistical process control (SPC), or, when a complete control is not performed on the most important product characteristics, according

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to the point of view of the customers or the productive process.

Therefore, the knowledge on the influence of machining parameters on the performance of internal combustion automotive engines becomes of utmost importance, since there is a series of theories on the behavior of the region where the valve seating is located. Nevertheless, there is not extensive literature which clearly explains the contribution of shape errors and surface finishing parameters affected by the variation of these machining parameters on the performance of engine power.

The machining of valve seats is of critical importance not only for the determination of power but also of torque, since the correct seating of the valves assures the correct sealing, which is essential for the engine running. In this way, manufacturers of tools, assembling and machining equipment, noticed the need for assuring sufficiently robust processes which grant the required quality and production values.

In multiple valve engines the diameters are smaller and the materials to be machined are increasingly harder. These conditions and the aim for higher cutting speeds imply higher tool requirements in the process of machining [3].

For example, a larger feed rate can produce a decrease in tool productivity due to the increase in the contact areas and, consequently, an increase in the machining force and levels of vibration [1,4]. As a result, the machine tool becomes highly sensitive, influencing the parameters of surface topography, deteriorating the machined surface quality finishing [5]. On the other hand, when there is an increase in cutting speed there is an increase in temperature at the chip–tool interface, reducing the shearing resistance of the work material, thus reducing the forces needed to promote shearing. In this way, the surface finishing of the machined part can be improved.

The valve sealing surfaces are produced through cylindrical boring. The movements of cut and feed of the tool onto the part, which is not moving, together with the geometry of the tool will determine the profile of this seat. Therefore, certain conditions must be highlighted, as, for example, rigidity of the machine tool; the set involving tool holder and cutting tool must to be perfectly balanced, and the cutting parameters must be well defined (cutting speed, depth of cut and feed rate).

The general objective of this work is mainly to show the influence of the cutting speed, feed rate and depth of cut on the wear mechanisms and tool life of polycrystalline cubic boron nitride (PCBN) tools while boring the internal combustion engine admission valve seats obtained by powder metallurgy technique.

2. Experimental procedures

The admission valve seat is manufactured from a material obtained through powder metallurgy, specification M657BA.12T, according to a production standard from FIAT Automobile Spa, Italy. Table 1 shows some of the characteristics of this material. In the micrographic analysis, it has been found uniformly distributed perlite with copper and cementite on the periphery of the grains.

The seats are assembled on the cylinder head using a special assembling machine with a cooling process by means of liquid nitrogen at −196 °C. In this equipment there is a loading control for implanting and positioning the valve seats. These data are given to the microprocessor which analyzes, for example, whether the implantation load is compatible to the position in which the seat is being assembled.

The machining procedure is performed after the valve seat is assembled on the engine cylinder head, and Fig. 1 shows the scheme of a valve.

2.1. Description of the machine tool

2.1.1. Machine tool

The equipment used in this work is a transfer line for the production for the 1.3 16 V FIRE engine cylinder head from Fiat-GM Powertrain Ltd.

2.1.2. Cutting parameters

The tests were performed using two depths of cut, 0.1 and 0.2 mm, three feed rates, 0.0495, 0.055 and 0.0605 mm/rev, and three cutting speeds, 128.61, 160.77 and 192.92 m/min. Forty five parts were machined and separated into nine groups of five parts, each part receiving a number for identifying the performed tests. Each group was machined according to a combination of feed rate and cutting speed.

For each sub-group of parts to be machined, a fresh tool was used, and for each manufactured part, the evolution of flank wear (VB_{Bmax}) was measured up to the end of the tool life. The criterion for defining the end of tool life was based on the surface finish parameters and of the valve seats sealing

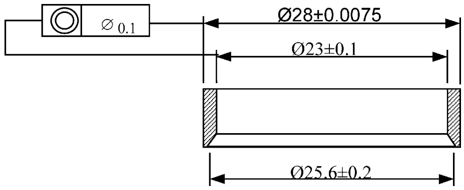


Fig. 1. Scheme of an admission valve seat (dimensions in mm).

Table 1
Chemical composition (wt.%), density and hardness of M657BA12T alloy

C	Mo	Ni	Cu	S	Cr	W	Fe	Other	Density (g/cm^3)	Hardness, HB (kgf/cm^2)
0.80–1.2	0.30–0.6	0.30–0.7	8.0–12.0	0.20–0.5	–	–	Balance	≥2.0%	≥7.0	220–320

Table 2
Characteristics of plantocool MH 2030 cutting fluid

Tests	Method	Values
Density at 20 °C	ASTM D 1298	1.005
pH of emulsion at 2% in water	MR 125	9.3
Emulsion aspect at 2% in water	MR079	Milky
BOSCH corrosion test, GG 25, at 2%	DIN 51360-2	No corrosion
Emulsion stability at 10% (min of 15 h)	MR 015	Estable
Product stability at 40/4 °C (min of 15 h)	MR017	Estable
Refraction factor	MR044	1.1

established by project. The number of heads produced per cutting tool within the project acceptance criterion, as R_a, R_q, R_z, R_t and W_t, was defined as tool productivity and is presently used as a parameter for measuring the cutting tool life. On other hand, since each head has eight admission valves, the real productivity, if necessary, can be considered as the number of machined heads multiplied by 8.

The tests were performed with MH 2030 EP cutting fluids, provided by Fuchs of Brazil S.A., highly lubricating, isempt of mineral oil. In its composition there is no nitrite, phenolic or chlorine-based biocides, cyanides or heavy metals, butilglicol, chloro-based EP additives, neither additives based on lead, barium or zinc. This fluid has 4–8% concentration, is biodegradable, non-toxic and non-irritating. Other characteristics can be seen in Table 2.

The equipment used for flank wear measurement (VB_{Bmax}), was an optical measurement inspection system manufactured by RAM Optical Instrumentation Inc., whose magnifying capacity is 150 times. The surface topography parameters were measured with surface texture measurement Perthen Mahr, model 58P 5.6. In this work crater wear was observed in some cutting conditions, but they were not measured because of their very small dimensions and for being difficult to measure them on the shop floor.

A system for monitoring the wear of the cutting tools was employed. Initially, the machine was run for approximately 30 min without cutting, so that all the mechanical components, hydraulic systems and other existing devices achieved the ideal work conditions. Following, the new cutting tools were positioned in the mandrills. After machining the first part, the tool was removed and the wear measured, always maintaining the equipment running so that the work conditions already attained were not lost. Returning with the tool to the machine, care was taken to position it always in the same place in order to avoid time or adjustment losses in the machine which could interfere in the tests. This procedure was repeated for each component. During the investigation, several vibration controls were performed aiming to evaluate the behavior of the equipment regarding its stiffness.

Again, with the objective of investigating the wear of the cutting tools, now during the process of normal machining, a monitoring of the wear/productivity of tools was performed in each case. The comparison of the tool wear values, measured at this stage, intrinsically indicates a larger or smaller interference of the cutting parameters. In this way, the final objective of this stage was the verification of the existence of a clear relationship among the cutting parameters and the tool productivity.

The PCBN tools were manufactured by De Beers in the form of small plates of 1.5 mm thickness, brazed on a cemented carbide substract. They presented a Knoop hardness of 2750 kg/mm^2, with CBN, from DBC50 grade in a approximate volume of 50%. The other elements were: 40% of TiC, 6% of WC and 4% of AIB_2/AIN.

The mounted tool presented the following geometry:

- clearance angle, $\alpha_0 = 10^\circ$;
- rake angle, $\gamma_0 = 5^\circ$;
- cutting edge angle, $\chi_r = 15^\circ$.

The tool life criterion used for cutting tools was a machined surface roughness $R_a = 1\,\mu$m.

3. Results and discussion

3.1. Wear mechanisms

The workpiece material presents chemical elements, as Ti and Al, with high solid solubility with elements presents in the tool material, as Cu, Ni and Mo [6,7]. This fact suggests high level of adhesion in the tribological system and, moreover, associated with low cutting speeds used, the attrition wear [4] phenomena is possible to occur. The attrition involved adhesion on the worn surfaces and loss of this material in a phenomena characterized by stick-slip.

Using the cutting parameters $f = 0.055$ mm/rev, $v_c = 160.77$ m/min, doc $= 0.1$ mm the best wear condition was obtained. The worn surfaces were evaluated and photographed in a scanning electronic microscope.

It can be observed in Fig. 2 the tool rake face and clearance face surfaces subjected to the condition of best performance.

It can be noticed a smooth aspect, suggesting that the dominant wear mechanism was diffusion [4]. No tendency for shipping or micro cutting were noticed, which could be the result of the lack of toughness of the tool or of abrasion, respectively, on the examined regions.

Fig. 3 shows the results of the evolution of the flank wear of the tool, VB_{Bmax} and of the arithmetic average roughness, R_a, for the worst selection of cutting parameters doc $=$ 0.2 mm, $v_c = 128.61$ m/min and $f = 0.061$ mm/rev.

With the cutting parameters doc $= 0.2$ mm, $v_c = 128.61$ m/min and $f = 0.061$ mm/rev, the tool presented both flank wear and crater wear, as can be seen in Fig. 4. Analyzing the worn surfaces, it can be observed a rough aspect, suggesting that the craterization has been activated by the discontinuous chip flow, characterized by low v_c and which activated the attrition wear mechanism. In Fig. 4, it can be also observed the large flank wear accelerated by this

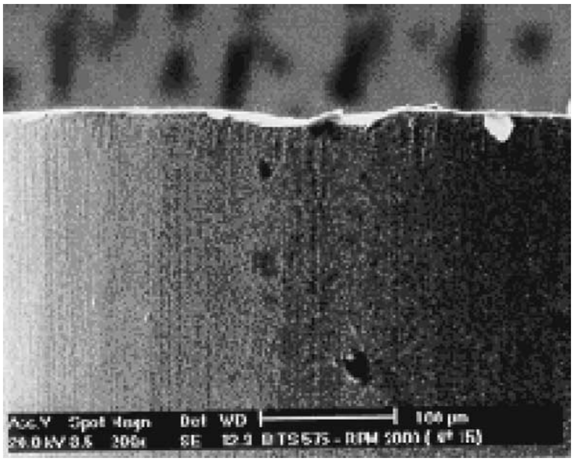


Fig. 2. Views of the clearance face of the worn tool with the best wear condition with cutting parameters: $f = 0.055$ mm/rev, $v_c = 160.77$ m/min, doc $= 0.1$ mm.

mechanism. The high values of the surface parameters indicate that the phenomena which takes place on the chip–tool interface does not occur in continuous and homogeneous form, and suggests the probable formation of built-up edge (BUE). Although it may be quite small in its instability and disappearance, it produces discontinuous chip flow and yields micro-burr on the machined surface worsening the finish surface.

Figs. 2 and 4 show the clearance and rake surfaces of the best and the worst tools performance, respectively. The tool which presented the best machined result ran at $v_c = 160.77$ m/min and showed a smooth aspect without evidence of cutting edge plastic deformation, which suggests that only the diffusion mechanism had happened. On the other hand, for the worst condition, $v_c = 128.61$ m/min, the cutting edge presents strong evidence of loss of material by the attrition mechanism. This mechanism is activated under discontinuous chip flow conditions, which happened at low v_c. Attrition produces continuous loss of material on the clearance and rake surfaces resulting in flank and crater forms of wear. The worn surfaces are noted by their rough aspect. Attrition is quite aggressive and the continuous loss of material results in large wear rates reducing the performance of the machining tribological system [4,5].

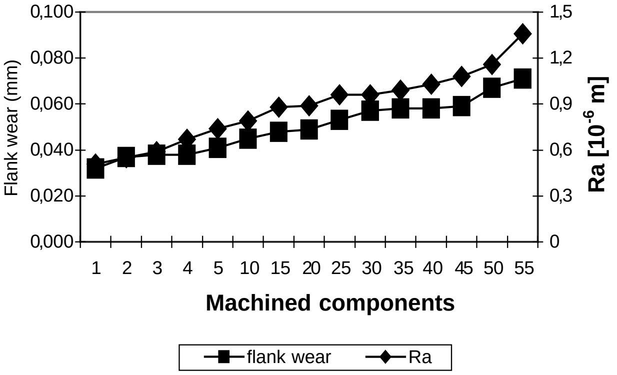
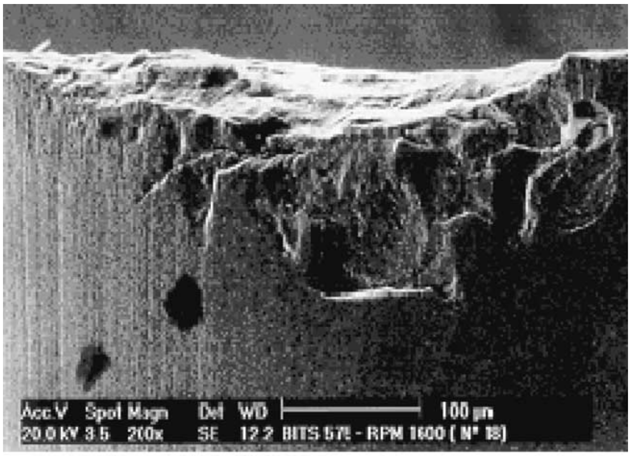
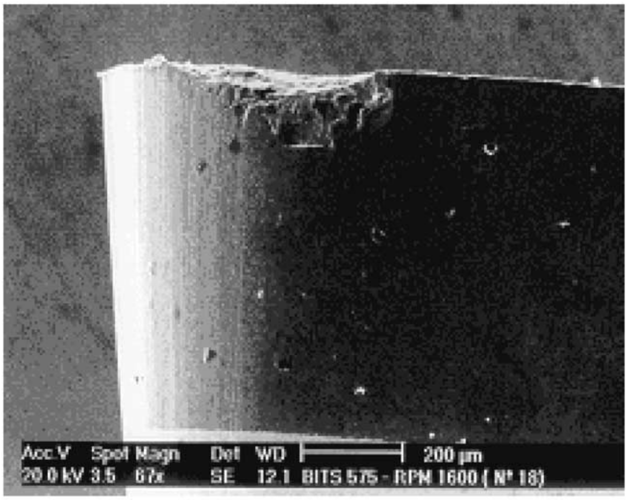


Fig. 3. Flank wear and surface finish against machined components for: doc $= 0.2$ mm, $v_c = 128.61$ m/min and $f = 0.061$ mm/rev.



(a) detail of the cutting edge



(b) clearance surface

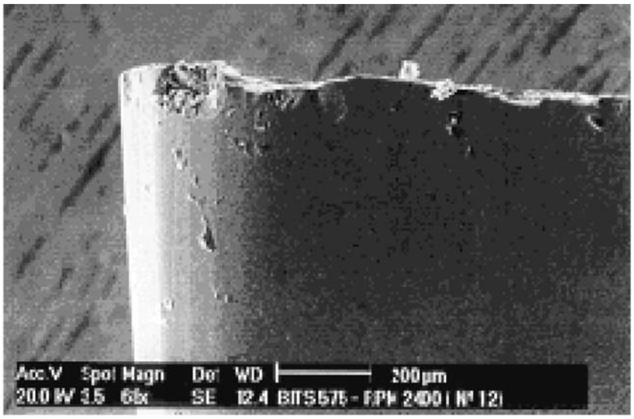
Fig. 4. Views of the tool worn in the best performance condition: doc $= 0.2$ mm, $v_c = 128.61$ m/min and $f = 0.061$ mm/rev.

A dynamic analysis was carried out on the system by measuring acceleration. By increasing order of instability, the accelerations were measured in the following cutting speeds: 160.77, 192.92 and 128.61 m/min, as it can be seen in Table 3. That is, at $v_c = 128.61$ m/min occurred large accelerations, which certainly produced discontinuity of the chip flow and promoted and accelerated the wear mechanisms.

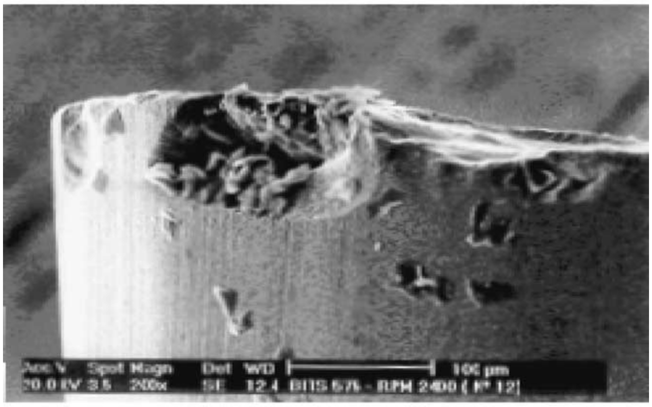
Fig. 5 shows the photographs taken from the intermediate performance condition. The machining parameters were:

Table 3
Synthesis of vibration analysis reports

Acceleration amplitude (m/s^2) for $v_c = 128.61$ m/min	0.521676
Acceleration amplitude (m/s^2) for $v_c = 160.77$ m/min	0.1023450
Acceleration amplitude (m/s^2) for $v_c = 192.92$ m/min	0.318060



(a) clearance face



(b) detail of de cutting edge

Fig. 5. Views of the worn tool in the intermediate performance condition: $f = 0.061$ mm/rev, $v_c = 192.92$ m/min, doc $= 0.2$ mm.

$f = 0.061$ mm/rev, $v_c = 192.92$ m/min, and doc $= 0.2$ mm. In this figure it is observed the severe flank and crater wear which occurred in the tool. There are evidences of chipping of the cutting edge, highlighted in part (a) of this figure. Observing the rake face, parts "a" and "b" of this figure, it can be noticed at a certain distance from the cutting edge, with a larger length than the cut depth (=200 μm), the evidence of chipping, that is, there has happened chipping of the material at the surface, which could be characterized as a damage [8]. For the verification of this phenomenon, it would be necessary to perform quick-stop tests which were not conducted in this work, since all the experimental part has been performed on the plant floor, the production line and in the boring process it would be very difficult to reproduce the situation under investigation.

The calculated chip–tool contact areas are:

- Best performance $= A_{s_1} = f \times \text{doc} = 0.055 \times 0.1 = 0.0055\,\text{mm}^2$ at $v_c = 160.77$ m/min.
- Poor performance $= A_{s_2} = f \times \text{doc} = 0.061 \times 0.2 = 0.0122\,\text{mm}^2$ at $v_c = 128.61$ m/min.
- The rate A_{s_1}/A_{s_2} is 0.45.

Under these circumstances, it is observed that the contact areas are very small. In comparing these cutting conditions, one can note that in the most favorable condition, although the area is smaller and all the phenomena related to the flow and generation of heat occurs on this reduced space, v_c is large. The cutting speed is the most influencing parameter in the temperature of the chip–tool interface [4]. In addition, the system is highly non-linear, that is, the increase of 25% on v_c (from 128.61 to 160.77 m/min) produced a great change on the behavior of the tribological system by completely changing its performance.

Other researchers [9] observed this type of behavior of PCBN tools machining hardened steels for the manufacturing of die casting milling at cutting speeds between 220 and 1320 m/min. They found evidences of diffusion in some tools and in other ones the presence of chipping mainly in tools with 65% of PCBN and 35% of metallic reinforcement which are recommended for finishing. According to them, diffusion has been predominant at the lower range of tested v_c, while chipping was at larger v_c. In one of their conclusions, they wrote that the main reason for failure of the tool with low volumetric percentage of CBN is the chipping of the main cutting edge.

According to the evaluation of the photographs of the worn tools shown in Figs. 2, 4 and 5, it is suggested that under the three conditions, the most significant wear mechanisms were:

- At $v_c = 128.61$ m/min—attrition and micro chipping—poor performance of the tool.
- At $v_c = 160.77$ m/min—light diffusion—best performance of the tool.
- At $v_c = 192.92$ m/min—chipping—intermediate performance of the tool.

It can be observed, in Fig. 6, at a constant depth of cut and cutting speed, that the increase in feed rate accelerates the wear of the tool. For the cutting speed $v_c = 128.61$ m/min it has been found the larger values of tool wear.

Analyzing the data obtained from the study of wear, presented in Fig. 7, for the same depth of cut value, it is observed that for the same cutting speed, the larger is the feed

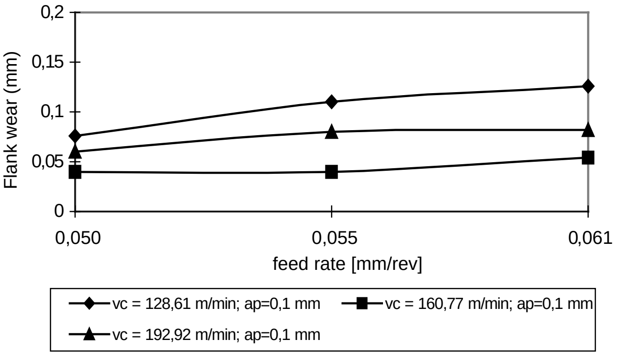


Fig. 6. Comparison of the wear of the tool with feed rate keeping fixed the depth of cut, doc = 0.1 mm.

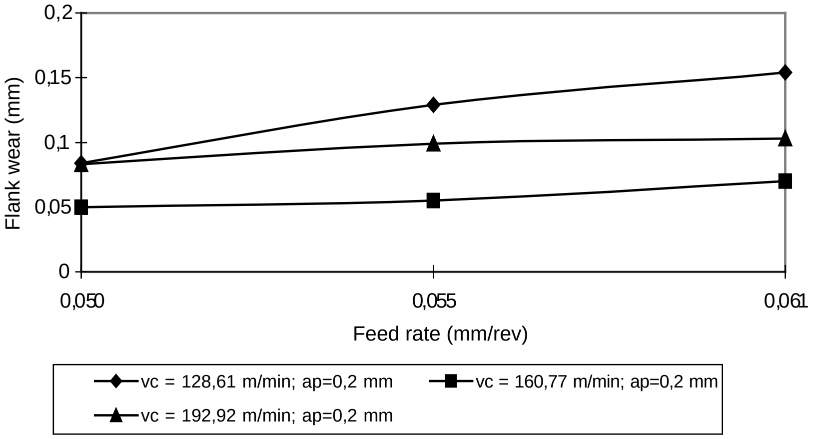


Fig. 7. Comparison of tool wear and feed rate keeping fixed the depth of cut, doc = 0.2 mm.

rate, the larger is the tool wear. The increase of the feed rate increases the chip–tool contact area, the rate of material removal and consequently the interface temperature [4,10]. In this way, the increase in the feed rate decreases the tool life.

Lim and Lim [11] presented a map for flank wear of coated and uncoated cemented carbide tools during single-point dry turning. Based on many researchers results, they showed the regions where the different ranges of wear rates are observed. Among all wear regions, they showed the possible existence of the safety zone, that is, the tribological system has very low wear rate. With the selected cutting parameters in this work, according to the above mentioned authors, the operation is in the least-wear regime.

Lim et al. [12], in other paper, present a wear map for flank wear of TiN-coated HSS inserts during dry turning operations. With the present parameters, according to the mentioned authors, the operation is from medium to high wear level regime.

With respect to the two above mentioned works [11,12], the present paper has some distinctions like the system vibration was identified, the machining occurred with abundant cutting fluid flow rate, and the tool material was PCBN with low fracture toughness which is it more sensitive to *f* vibrations and, consequently, to the chipping of the flank and rake tool surfaces. It is possible to characterize the map for flank wear on studied tribological machining system, but it was not the objective of this work.

At the depth of cut, doc = 0.2 mm, the analyses are similar to those presented for doc = 0.1 mm. For both the tests, keeping the same feed rate, the smaller is the cutting speed, the larger is the tool wear. Nevertheless, when it is applied the same cutting speed, v_c, the larger is the depth, the larger is the wear.

3.2. *Tool productivity*

For the same cutting speed, it is observed in Figs. 8 and 9 that the increase of the feed rate decreases the productivity of the tool for given cut depth, although very small for the optimal cutting speed and lower cut depth.

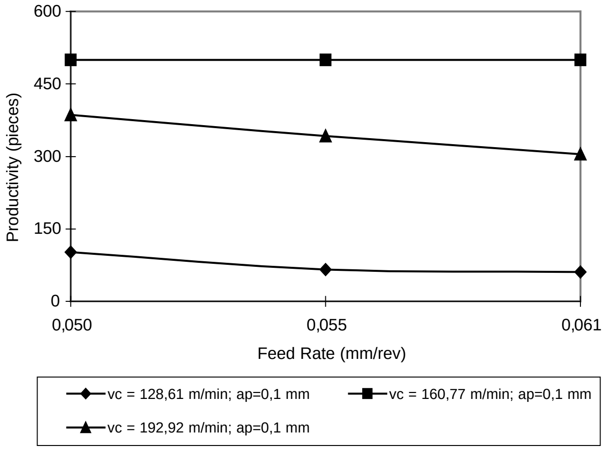


Fig. 8. Comparison of tool productivity with feed rate and cutting speed keeping fixed the depth of cut, doc = 0.1 mm.

The analysis of productivity is directly related to the tribological behavior of the machining system, that is, smaller wear rates lead to larger productivity and vice-versa.

The tool, which was PCBN with 50% of metallic secondary phase, showed to be quite sensitive to the variation

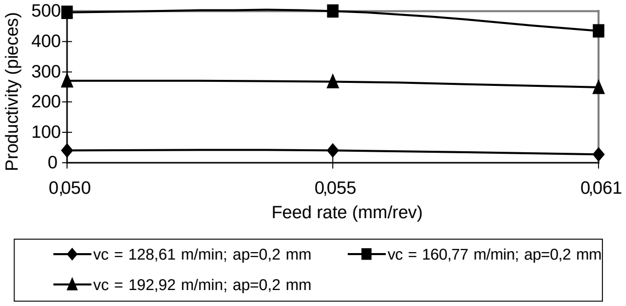


Fig. 9. Comparison of tool productivity with feed rate keeping fixed the depth of cut, doc = 0.2 mm.

of the cutting parameters, mainly to the cutting speed and feed rate. As in the case of v_c, small incremental changes of 15%, for more or less around the average (160.77 m/min), produced a large change in performance of the tribological system. The worst condition produced approximately 30 parts, while the best produced 500 components. This suggests that there has been a transition between wear mechanisms like attrition, which predominates in conditions of low v_c where the chip flow is intermittent and the chipping occur. At the largest cutting speed tested (192.92 m/min) it has not been in evidence, in the analysis though scanning electronic microscopy, the diffusion, which is exponentially dependent on the temperature [4,11], which, by its turn, is strongly influenced by the cutting speed [5].

3.3. *Influence of the cutting parameters*

The sealing test measures the air escape to pressure and the standard flow which occurs between the valve and its seat. The test isolates the admission and exit valves allowing to obtain information from each one. A good sealing means that the isolation between valve and seat allows the smallest passage of gases through the contact zone.

The seat-valve contact theoretically processes itself along a circumference. Physically, this happens due to the geometric difference between the angles of the valve and their seat. Nevertheless, the micro irregularities can be approximated due to the radius and the height (h) [6]. Hence, the roughness geometry has an importance in the retention property necessary to the tribological system.

During the machining process, for example, a larger feed rate can produce an increase in the chip–tool contact areas and consequently an increase in the machining force and vibration levels [13]. Thus, the machine tool becomes highly sensitive, influencing the surface topography parameters, worsening the machined surface finishing which certainly interferes in the sealing of the valve on the machined surface and which directly affects the engine performance. On the other hand, when there is an increase in the cutting speed there is an increase in the temperature in the chip–tool interface, decreasing the shear resistance of the material and therefore decreasing the forces necessary to forward the shearing. In this way, the surface finishing of the machined surface which produces an increase in the support rate can be improved, which results in a better sealing of the valves on the machined seat. The relation between roughness, R_a, and the measured gas flow rate is illustrated in Fig. 10.

An analysis of Fig. 10 shows that an increase in the roughness R_a results in an increase in the air loss in the interface between the surfaces of the valve and the seat in the contact region. The arithmetic average roughness R_a is a poor statistical parameter to describe the state of the surface topography. Two surfaces with the same R_a can present very different topographies. A more trustworthy evaluation leads to the simultaneous analysis among R_a, R_q, R_t and W_t [14–16].

In this section, in order to analyze the relationship between the surface topography and the sealing capacity, the other parameters mentioned above and the Abbott–Firestone curves representative of each surface were plotted. Surfaces with a good support relation must present the smallest possible inclination in the central region of this curve. That is, the ideal sealing surface should present a line parallel to the abscissa axis and the real and apparent contact areas would be alike. In this way, there would be no regions for the loss of gases and the sealing would be effective [14,15].

The results obtained with the roughness measurement system showing surface profile, the values of R_z, R_a, R_q, R_t, W_t and the curve of Abbott–Firestone (DIN 4776 [16]) representative of the profile, are presented in Figs. 10–14. Fig. 11 corresponds to point “A” marked in Fig. 10.

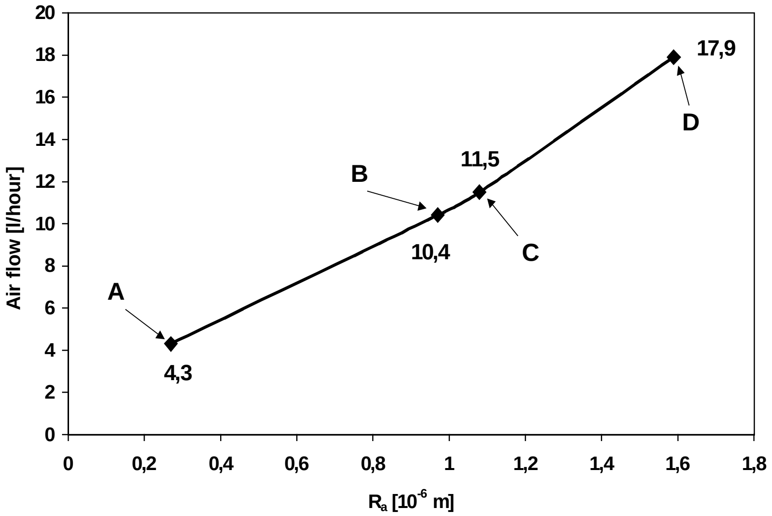


Fig. 10. Relation between roughness R_a and gas flow rate measured in the sealing test.

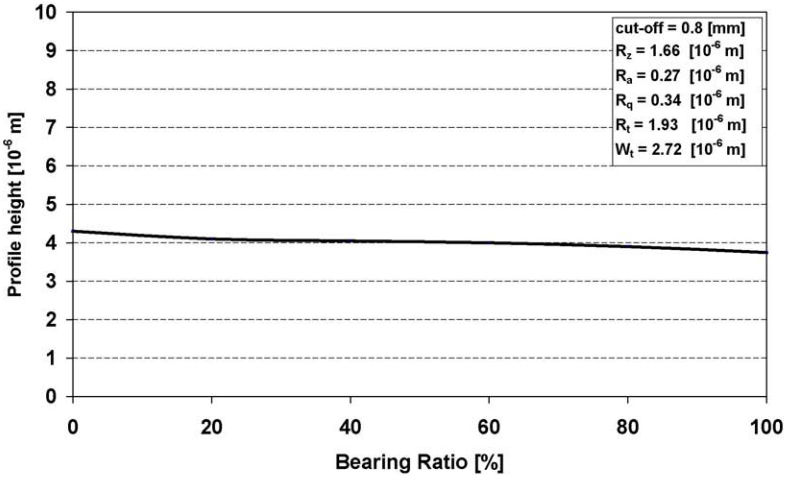


Fig. 11. Roughness profile and Abbott–Firestone curve for point “A”.

In Fig. 11 it can be observed that, for $R_a = 0.27\,\mu\text{m}$, the Abbott–Firestone curve is quite plain, that is, the support relation is high which produces a good sealing [12]. The air loss in the sealing test shown in Fig. 10 was 4.3 l/h.

Fig. 12 corresponds to point “B” marked in Fig. 10. It can be observed for $R_a = 0.97\,\mu\text{m}$ that the Abbott–Firestone curve has an inclination in the central region stronger than that of Fig. 11 ($R_a = 0.27\,\mu\text{m}$) which is quite plain. That is, the support relation is smaller. This produces a little bit worse a sealing. In this case, the air loss in the sealing test, shown in Fig. 10, was 10.4 l/h.

Fig. 13 corresponds to point “C” marked in Fig. 10. In this figure, it can be observed for $R_a = 1.08\,\mu\text{m}$ that the Abbott–Firestone curve has an inclination in the central region stronger than that of Fig. 12 ($R_a = 0.97\,\mu\text{m}$). Therefore, the support relation decreased and impaired the sealing. In this case, the air loss in the sealing test shown in Fig. 10 was 11.5 l/h.

Finally, Fig. 14 corresponds to point “D” marked in Fig. 10. It can be observed for $R_a = 1.59\,\mu\text{m}$ that the Abbott–Firestone curve has a strong inclination in the central region, greater than in Fig. 11 ($R_a = 0.27\,\mu\text{m}$). Since, the support relation further declines inferior and has increasingly impaired the sealing. The air loss in the sealing test shown in Fig. 10 was 17.9 l/h.

It can be observed in Figs. 11–14 that the behavior of R_z, R_q and R_t follows that shown by R_a. In the same way, an increase in R_q and R_t produces a decrease in the support rate and, consequently, an increase in the air losses measured by means of the sealing test.

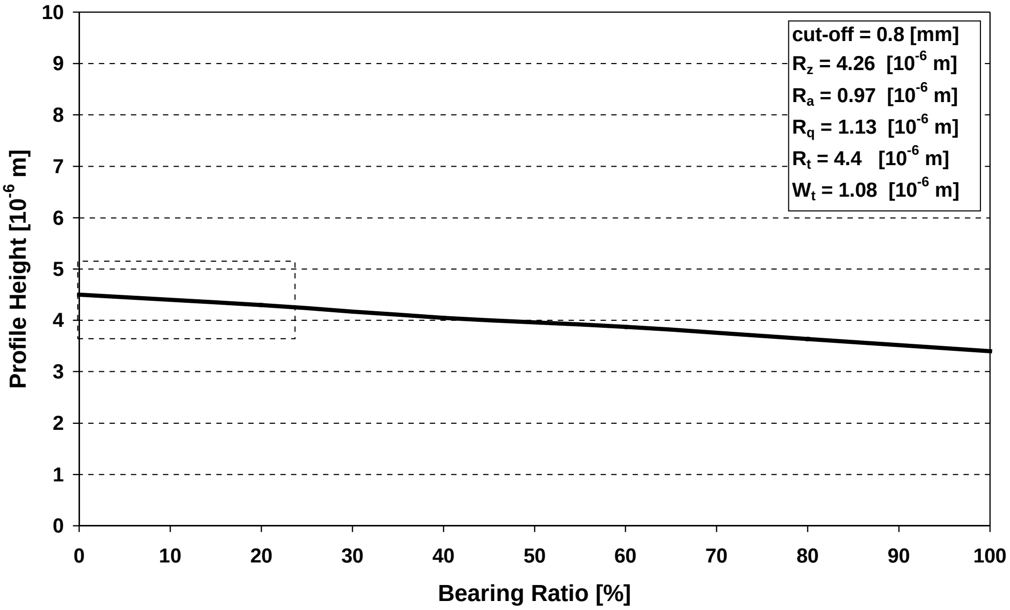


Fig. 12. Roughness profile and Abbott–Firestone curve for point “B”.

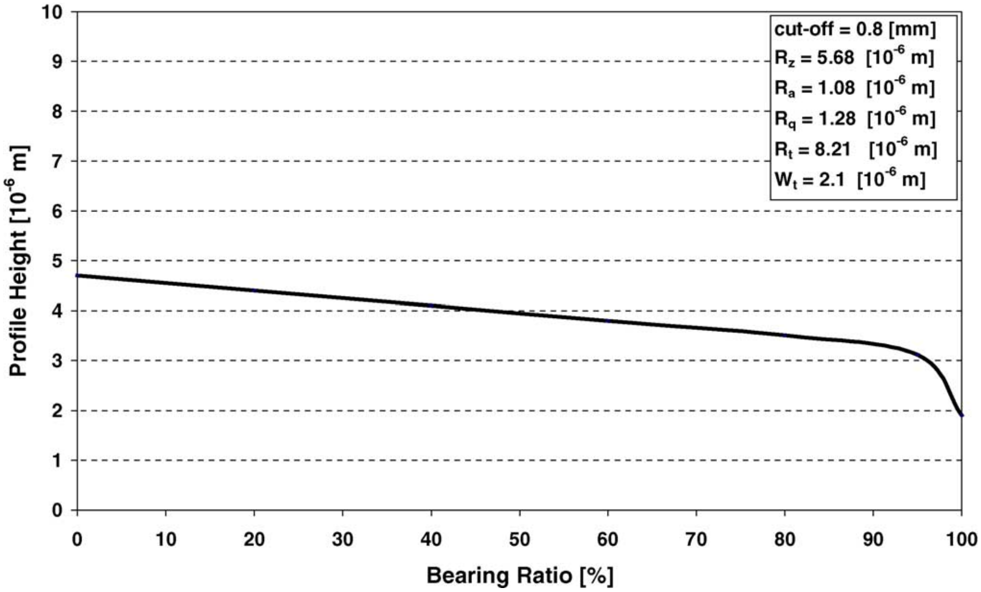


Fig. 13. Roughness profile and Abbott–Firestone curve for point “C”.

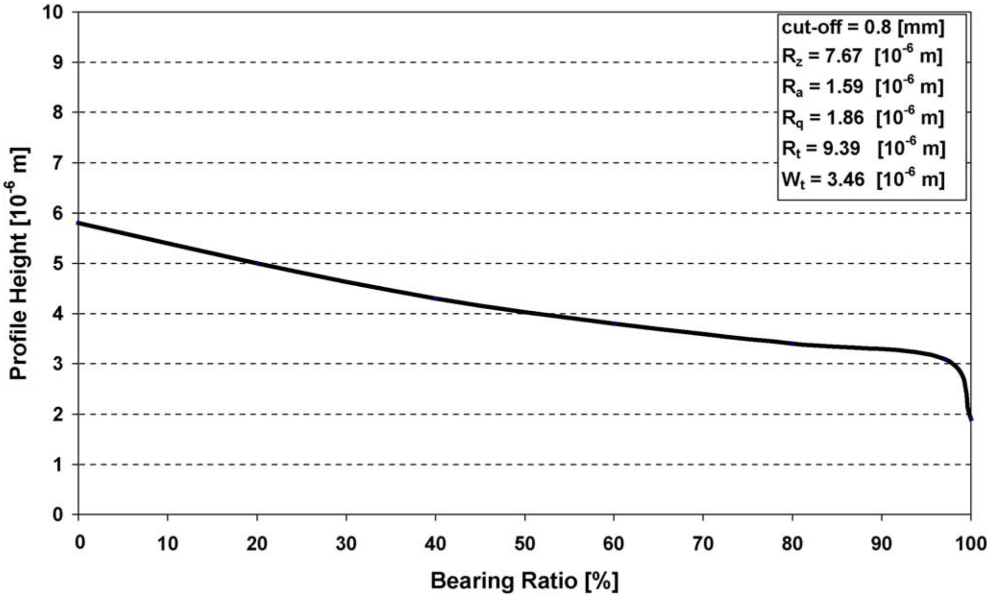


Fig. 14. Roughness profile and Abbott–Firestone curve for point “D”.

Regarding the ondulation (W_t), there has been a tendency to increase with R_a, R_z, R_q and R_t, except at point A in Fig. 10 where it has been obtained the high W_t value, but the best result can be due to a combination with low R_z, R_q and R_a and W_t values, shown in Fig. 11, also resulting in an increase of air loss. The fluctuations among the observed parameters were the factor less influent in the sealing characteristics. Other parameters directly show how the contact is going to happen in the contact points, while W_t shows the deviations in a larger order of magnitude, which makes it directly associated to the capacity of sealing, nevertheless in a quite smaller scale.

Since R_a, R_q and R_t show the surface aspects of the machined surface and the zone where the contact will take place, they indicate how the contact is influenced by them, determining that the better this contact is, the better is the sealing and, consequently, the better is the performance, since in the moment when there is the explosion, this system shall have the smaller possible losses of gas, granting the complete use of the mixture and generating greater power.

4. Concluding remarks

It was observed in this work that cutting parameters influence the tribological performance. It is simultaneously based on the dynamical characteristics of the tool machine and the phenomena occurring in the chip–tool interface.

The productivity of the tools decreases with an increase in the feed rate and the worst condition relating tool productivity was doc $= 0.2$ mm, $v_c = 128.61$ m/min and $f = 0.060$ mm/rev where the predominant wear mechanism was attrition. The best condition was $f = 0.055$ mm/rev, $v_c = 160.77$ m/min, doc $= 0.1$ mm and the predominant wear mechanism was diffusion. An increase in depth of cut increases the wear, activating the mechanisms present in the interaction with the cutting speed and, a change in the cutting parameters directly influences the behavior of the tribological system as well as the vibration level, and the cutting speed is the most influencing parameter. An increase in the support rate, determined by means of the Abbott–Firestone curve, decreased the air losses measured in the cold dynamic test and, an increase in ondulation showed a tendency of increasing the air losses, decreasing the sealing. An increase in the feed rate and depth of cut increased the average roughness of the surface, R_a, while an inverse behavior was found for the cutting speed and, the feed rate was the most influencing on the surface finishing. It is suggested that at low cutting speed attrition has predominated, at medium diffusion and at high the PCBN tool presented several micro chipping. The flank wear was the dominant form of wear in PCBN tools. An increase in this wear, VB_{Bmax}, produced an increase of roughness of the valve seat. A decrease in R_a, R_q, R_z, R_t and W_t increased the support rate and consequently the air losses and, for low air flow rates, it is desirable to maintain these parameters in smaller values.

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References

[1] M.P. Groover, Fundamentals of Modern Manufacturing: Materials, Processes, and Systems, Prentice-Hall, Englewood Cliffs, NJ, 1996. ISBN 0-13-312182-8.
[2] M.M. De Sousa, Use of mechanical vibrations for the monitoring of tool wear and surface roughness on milling process, Ph.D. Thesis, Federal University of Uberlândia, UFU, Uberlândia, Minas Gerais, Brazil, 1998 (in Portuguese).
[3] C.A. Rocha, Effect of the cutting parameters on the internal combustion motor valve seat machining using PCBN tools, Master Science Dissertation, Pontifical Catholic University, PUC Minas, Belo Horizonte, MG, Brazil, 2000 (in Portuguese).
[4] E.M. Trent, Metal Cutting, 3rd Edition, Butterworths, London, 1991, 273 pp. ISBN 0-7506-1068-9.
[5] A.R. Machado, M.B. Da Silva, Metal Cutting, Editora UFU, Universidade Federal de Uberlândia, Uberlândia, MG, Brazil, 1999 (in Portuguese).
[6] I.M. Hutchings, Tribology: Friction and Wear of Engineering Materials, CRC Press, Boca Raton, USA, 1992, 273 pp.
[7] J.A. Williams, Engineering Tribology, Oxford Science Publications, 1996. ISBN 0.19.856503.8.
[8] P.A. Dearnley, E.M. Trent, Wear mechanisms of coated carbide tools, Met. Technol. 9 (1982) 60–75.
[9] M.A. Elbestawi, L. Chen, C.E. Becze, El Wardary, High-speed milling of dies and molds in their hardened state, Ann. CIRP 16 (46/1) (1997).
[10] M.C. Shaw, Metal Cutting Principles, Oxford University Press, Oxford, 1984. ISBN 0-19-859002-4.
[11] S.C. Lim, C.Y.H. Lim, Effective use of coated tools—the wear-map approach, Surf. Coat. Technol. 139 (2001) 127–134.
[12] S.C. Lim, C.Y.H. Lim, K.S. Lee, The effects of machining conditions on the flank wear of TiN-coated high speed steel tool inserts, Wear 181–183 (1995) 901–912.
[13] G. Boothroyd, Fundamentals of Metals Machining and Machine Tools, International Student Edition, 5th printing, McGraw-Hill, New York, 1981, 350 pp.
[14] L. Mummery, Surface Texture Analysis: The Handbook, Hommelwerke, GmbH, 1992.
[15] H. Dagnall, Exploring Surface, Taylor Hobson Handbook, Leicester, UK, 1998.
[16] DIN 4776, Measurement of Surface Roughness Parameters R_k, R_{PK}, R_{VK}, M_{r1}, M_{r2} for Description of the Material Portion (Profile Length Ratio) in the Roughness Profile Measuring Conditions and Evaluation Procedures, 1990.