COMPARISON BETWEEN TURNING AND GRINDING PROCESS APPLIED TO PRODUCE SINTERED CEMENTED CARBIDE SAMPLES

Nivaldo Lemos Coppini, ncoppini@uninove.br
Marcelo Bonandi, marcelo.bonandi@uninove.edu.br
José Carlos Curvelo Santana, jccurvelo@uninove.br
Elesandro Antonio Baptista, elesandro@uninove.br
Mayara Aparecida Gomes da Silva, mayaragsilva@uninove.edu.br
Universidade Nove de Julho, Av. Francisco Matarazzo, 612, Barra Funda, 05001-100, São Paulo, SP, Brazil

Abstract. *The demand for parts and components with adequate properties and durability has become a challenge to their manufacturers worldwide. For companies in this sector, ensuring success in the market means to promote the efficient production of high quality products with adequate mechanical properties. Moreover, it is possible to find that the literature specially dedicated to publish results in the cutting process segment, has devoted a relatively intense attention to how to cut hardened materials, especially hardened steels. The focus has been to replace grinding process applied after heat treatments for processes that use tools with defined geometry cutting edges such as turning. It is very known the use of cemented carbides to produce cutting tools. It is relatively known, as well, that this kind of material is cut before the sinterization process incidence, to produce special tools or specific kind of parts, which will be sintered later. What is not very known is to cut cemented carbides to produce special kind of parts used when high hardness and high compression resistance is demanded. It is very common to use the grinding process to finish cemented carbide parts. What is not common is to finish sintered cemented carbide parts by the use of turning process. So, it was possible identifying a gap in the literature and was found that recent research does not focus on the cemented carbide turning process and its benefits when compared with the grinding process to produce samples of this material. Therefore, strive for high excellence with production tools and cutting parameters can be a competitive differentiator for many companies in each market. So, the question that arises is the following: "is hard turning process more efficient compared to the grinding process used to produce cemented carbide samples?" To answer this question the authors prepared an experience to be developed in shop floor of an industry that choose not to be identified. The results obtained include specific quality of a machining surface but also roundness. As the grinding process was already optimized, the cutting conditions for this operation was taken that in use, as to say, no grinding conditions were parameterized.*

Keywords*: Hard Turning; Sintered Cemented Carbide; Grinding;*

1. INTRODUCTION

Producers of machined components and manufactured goods are continually challenged to reduce cost, improve quality and minimize setup times in order to remain competitive. To be excellent in terms of production machining processes can be a competitive differentiator for sintered cemented carbide manufacturing companies. Such is the case with grinding where the traditional operations involve expensive machinery and generally have long manufacturing cycles, costly support equipment, and lengthy setup times, especially to grind sintered cemented carbide. These applications often require new ideas and different methods as a hard turning process which is best performed with appropriately lathes and tools. The successful machining performance is affected by work material properties. The properties as well as the characteristics of work materials are assessed in terms of ''machinability", which indicates the relative ease with which a material can be machined using a proper cutting tool and the process parameters. The most common criteria to assess the machinability are force, power, specific cutting force, tool life, tool wear and surface roughness. According to Groover (1996) although the machinability refers to work materials, the performance of machining depends upon several variables such as cutting parameters, tooling and machining operations.

To the best of the knowledge of the authors, there are few studies examining benefits and impacts of hard turning in cemented carbide. Further, no systematic studies have been reported to analyze the effects of process parameters on machinability and the advantages compared with grinding process. Hence, an attempt has been made in this paper to assess the machinability characteristics in terms of grinding and hard turning process using diamond tools for sintered cemented carbide parts relate to the total operation in terms of part quality and surface roughness.

2. LITERATURE REVIEW

According to Konig *et al.* (1993) the hard turning technique is new and the management of this process is still limited. For more than a decade, use of hard turning has been increasing in a range of industrial applications. Precision finish turning has the potential to replace grinding in some applications. The cutting operation is controller by the parameters v_c (cutting speed), a_p (depth of cut) and f (feed rate).

According to More *et al.* (2006) PCBN (polycrystalline cubic boron nitride) is the material most commonly used in tools for hardened steel turning applications due to it's high hardness, wear resistance and thermal stability (More *et al.*, 2006). Diamond tool is widely used in tooling industry, where it is applied on materials, which are too hard to be machined with conventional techniques.

As a definition, hard turning process is the effective finish turning of hardened materials 45HRc or more with single point turning tools. Through or case hardened steels up to 64 HRc, even finish sintered tungsten carbide up to 68 HRc have been successfully turned on lathes. According to Oliveira *et al.* (2009) parts with hardness exceeding 45 HRC can be machined by hard turning, which provides surface roughness, dimensional and shape tolerances similar to those achieved in grinding.

In an ideal scenario grinding processes would be eliminated, since the economic point of view is not very productive and extremely expensive. However, many parts need be finished after heat treatment in this type of process, due to their employment. Historically, the hard grinding process is done by grinding with grinding wheels, either in roughing or finishing. To replace this process, the hard turning has to be able to generate geometric accuracy and surface quality compatible with the grinding. Some studies have demonstrated the capability of the hard turning process to produce surface finish and dimensional accuracy that can replace the grinding, especially for steel parts. Abrão *et al.* (1995) produced steel parts with a surface roughness equal to Ra = 0.14mm turning parts as a H13 or AISI E52100.

According to Navas (2008) in hard turning process the dominant factor is the thermal effect, which generates tensile stresses at the surface due to higher toughness of the cemented carbide, thus, it is not difficult to understand why some of the limitations of this type of work concerns the cutting tools. As Fig. 1, the ideal cutting tool must be at the top right with higher resistance and the CVD appears as a option for this application. According to Navas (2008), the precision and rigidity of the machines are also an important key of success of this process.

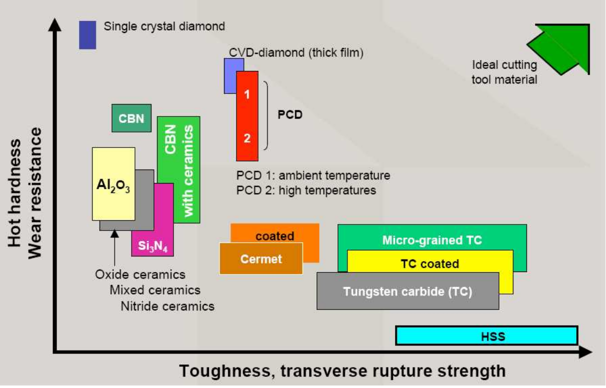


Figure 1. Cutting tool materials.

It is known that the tools have been improved so that the hard turning could become a viable process. Due to the sharp negative rake angle tools used for machining of hardened materials appear high cutting forces. They require adequate rigidity of the machine tool, power in the spindle, damping characteristics and precision in movement and positioning of the axes. Modern machine tools are already incorporating the latest technologies such as machine-based polymer composites, reducing the number of attachment points, hydrostatic guides, among other developments. Electronically the development of numerical controls more capable also significantly influenced the accuracy of machine tools.

3. METHOD

In order to meet the policy of confidentiality of information in business object case study, the process names and their respective products have been modified in this study. In addition, the company is called "XYZ". The company XYZ is a multinational company tool maker. It is a group based in high-tech engineering and stands with the pioneering markets it serves through a combination of leading companies in their segments, always in search for excellence of products and services offered to its customers and partners through research, development, design, manufacturing and marketing of high technology. It works in partnership with research centers in the U.S. and abroad, encouraging technological and educational initiatives.

The method applied during this work was experimental and was developed completely in shop floor.

The work material selected for the current study is a 12% Co tungsten cemented carbide used as samples. The chemical composition, mechanical and physical properties is given Tab. 1. The microstructure of material used in the present investigation is shown in Fig. 3.

The preliminary investigations carried out revealed that the chemical vapor deposition diamond (CVDD) cutting tools have showed a higher wear resistance for dry machining of tungsten cemented carbide, therefore, diamond tools were used for a hard turning under the following conditions: cutting speed 10 and 30 m/min; feed rate 0.15 and 0.20

mm/rev and two different depth of cut 0.25 and 0.50 mm. Figure 2 show the geometrical details for a diamond tool applied under dry condition with these parameters. As a comparison, a cylindrical grinder Ferdimat U-71 with a diamond grinding wheel D91 was applied with the following parameters: cutting speed 1780 m/min; feed rate 60 mm/rev and depth of cut 0.10 mm.

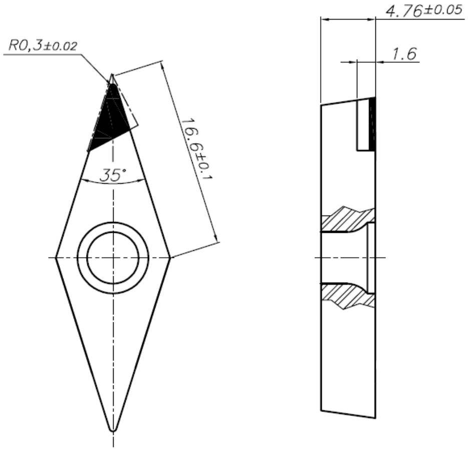


Figure 2. Geometrical details for the CVDD tool applied.

A conventional hard turning process and a production grinding process were applied over cylindrical pieces of the same series of cemented carbide to remove 1 mm of stock metal. The 66 mm diameter and 101 mm length work pieces were used for the experimentation. From each machined bar a slice was obtained from which the analysis was done. An aspect of the sample used for a test is shown in Fig. 4. The experimental work was carried out on a high rigidity Okuma LB300 CNC lathe, equipped with 22 kW spindle power and maximum main spindle speed of 5000 RPM. This Lathe has a good performance in the shop floor and high structural rigidity.

Table 1. Chemical composition, mechanical and physical properties of the sample.

Nominal Chemical Composition		
Cobalt		12.00%
Tantalum Carbide		0.20%
Nominal Physical Properties		
Hardness	ASTM B-294	89.6 Ra
Density	ASTM B-311	14.3 g/cc
Transverse Rupture Strenght	ASTM B-406	595,000 psi
Fracture Tougness	ASTM B771-87	13.2 MPa.m$^{0.5}$
Wear	ASTM G-65	7.0 mm^3
Compressive Strength		640,000 psi
Grain Size		2 µm

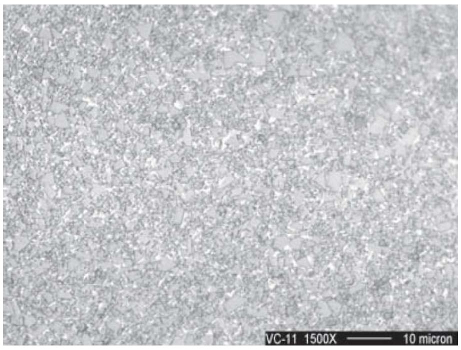


Figure 3. Microstructure (1500x).

Figure 4. Sample used: 66mm x 101mm.

The cutting speed (v_c) and feed rate (f) were selected as the machining parameters and the ranges of the parameters were identified through the preliminary experiments. Two levels for cutting speed (10 and 30 m/min) and two levels for feed rate (0.15 and 0.20 mm/rev) were selected for a hard turning process. Two different depth of cut (a_p), 0.25 and 0.50 mm under dry machining has been employed throughout the study. Indicated in Fig. 5 are the output measurement details. The eight trials based on full factorial design (FFD) of experiments were planned according to Montgomery

(2003). The layout plan as per FFD for the present investigation is given in Tab. 2. The trials were randomized to avoid the error creeping into the system. The machining parameters employed are summarized in Tab. 2.

Table 2. Hard Turning Parameters and Grinding Parameters and Full Factorial Design

Hard Turning Process						
Machining Parameters	-1	1		Factorial Design		
				f (mm/rev)	a_p (mm)	v_c (m/min)
Feed Rate (*f*)	0.15	0.20		-1	-1	-1
				1	-1	-1
Depth Cut (a_p)	0.25	0.50		-1	1	-1
				1	1	-1
				-1	-1	1
Cutting Speed (v_c)	10	30		1	-1	1
				-1	1	1
				1	1	1

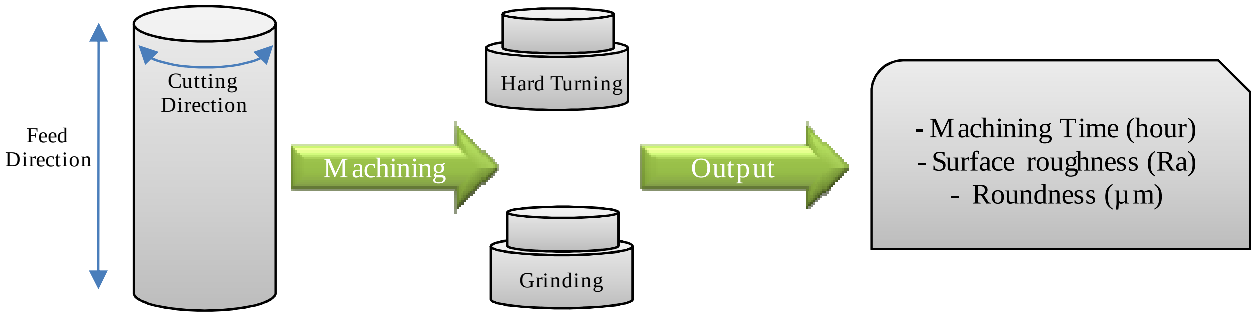


Figure 5. Obtaining the samples, machining process and output expected analysis

The Mitutoyo SJ-401 Rugosimeter was employed to measure the surface roughness parameters such as arithmetic average surface roughness (Ra). The acquisition of surface roughness was made by a output of hard turning and grinding process. Each trial was repeated twice and the average of two measurements is the response value. The surface roughness of the work materials was measured with 0.8 mm cut off value. The roughness was measured at two equally spaced locations around the circumference of the work pieces and the average was taken as the process response. The temperature of environment for both measures was 20 ±1ºC. For the roundness analysis, the Mahr TalyRound Circularimeter was employed and the acquisition of results followed the same procedures as above.

4. RESULTS AND DISCUSSIONS

The various combinations of the cutting regime parameters (v_c, *f* and a_p) are used for specific correlations as shown in Tab. 3. Such correlations have already been tested for roughness and roundness measurements.

Table 3. Roughness and roundness output as a function of the experimental plan for Hard Turning.

Parameters							Criteria / Values					
Codified Values				Actual Values			Roughness			Roundness		
Test	X_1	X_2	X_3	*f*	a_p	v_c	Ra_1	Ra_2	$Ra_{Average}$	C_1	C_2	$C_{Average}$
1	-1	-1	-1	0.15	0.25	10	0.24	0.22	0.23	0.76	0.75	0.76
2	1	-1	-1	0.20	0.25	10	1.16	1.19	1.17	0.80	0.82	0.81
3	-1	1	-1	0.15	0.50	10	0.33	0.29	0.31	1.15	1.13	1.14
4	1	1	-1	0.20	0.50	10	1.73	1.72	1.72	1.22	1.22	1.22
5	-1	-1	1	0.15	0.25	30	0.19	0.18	0.18	0.72	0.72	0.72
6	1	-1	1	0.20	0.25	30	1.04	1.07	1.05	0.75	0.77	0.76
7	-1	1	1	0.15	0.50	30	0.28	0.26	0.27	1.12	1.11	1.12
8	1	1	1	0.20	0.50	30	1.56	1.52	1.54	1.18	1.16	1.17

It is seen from this Tab. 3 that the roughness is highly sensitive to feed rate variations. Further, the lowest value of roughness can be identified with lower feed rate and depth of cut, however, with the highest cutting speed. The magnitude of cutting speed is similar to depth force but smaller as compared to feed rate for roundness analysis. In the other side, the roundness is much more sensitive to depth of cut, probably due to vibration or excessive cutting effort.

The results for a grinding process were checked monitoring the current process used and its results of roughness and roundness are 0.19 Ra and 0.70 µm as showed in Fig. 6 and 7 respectively. However, the total cycle time was 1.5 hours instead of 0.5 hours for a hard turning process.

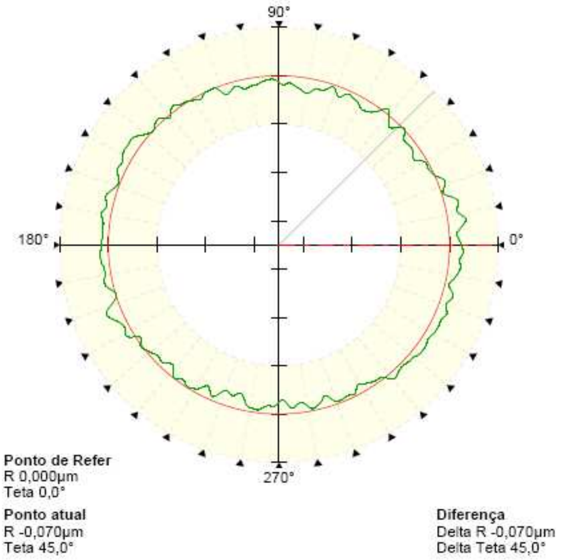
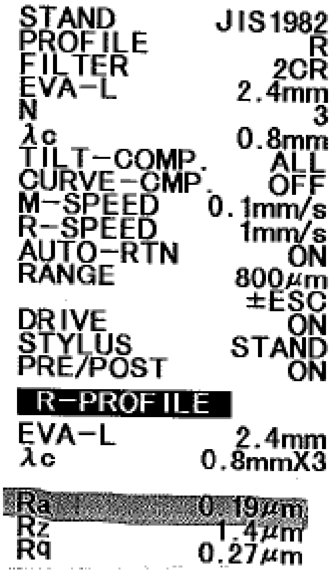


Figure 6. Roundness measure output for a current grinding process



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STAND          JIS1982
PROFILE              R
FILTER             2CR
EVA-L            2.4mm
N                    3
λc               0.8mm
TILT-COMP.         ALL
CURVE-CMP.         OFF
M-SPEED       0.1mm/s
R-SPEED         1mm/s
AUTO-RTN            ON
RANGE           800µm
                  ±ESC
DRIVE               ON
STYLUS           STAND
PRE/POST            ON
 R-PROFILE
EVA-L            2.4mm
λc             0.8mmX3

Ra              0.19µm
Rz               1.4µm
Rq              0.27µm
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Figure 7. Roughness measure output

The 3D surface graphs for cutting speed, feed rate and depth of cut with respect to roughness are presented in Fig. 8, 9 and 10. As seen from Fig. 8 the variation of roughness with the cutting conditions is linear and found to be increase with feed rate for a given value of depth of cut. Further, the roughness decrease with increase in cutting speed particularly at lower feed rates as seen from Fig. 10.

It is also observed that the roughness is almost insensitive to cutting speed variations and depth of cut, as seen from Fig. 9 and the roughness is lower mainly when the feed rate is under control. It is worth mentioning here that, the roughness will be small at a combination of higher cutting speed and lower feed rates and depth of cut.

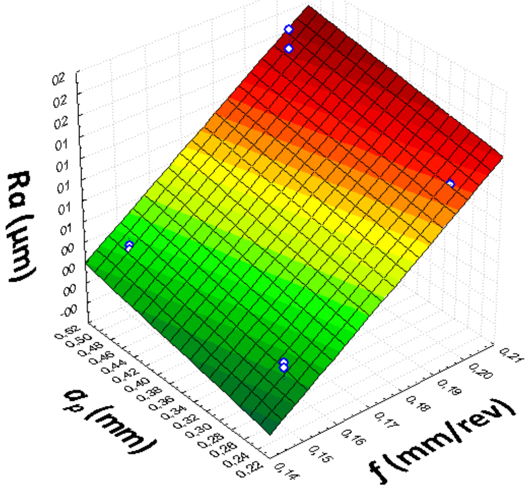

Figure 8. Response surface plot showing the effect of depth of cut and feed rate for Roughness.

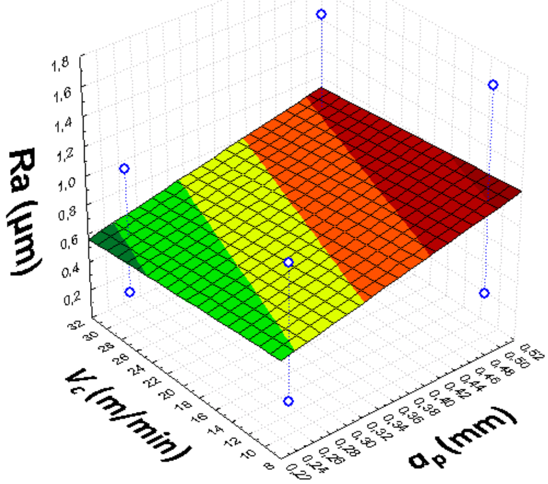

Figure 9. Response surface plot showing the effect of cutting speed and depth of cut for

Roughness.

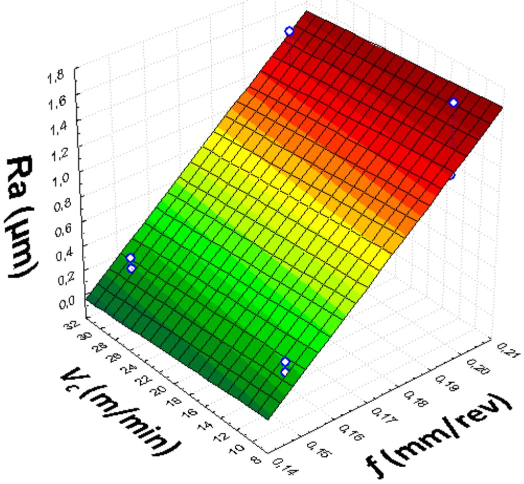

Figure 10. Response surface plot showing the effect of cutting speed and feed rate for Roughness.

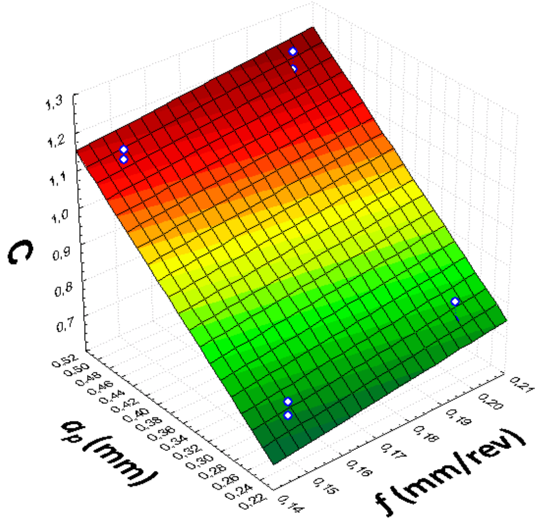

Figure 11. Response surface plot showing the effect of depth of cut and feed rate for Roundness.

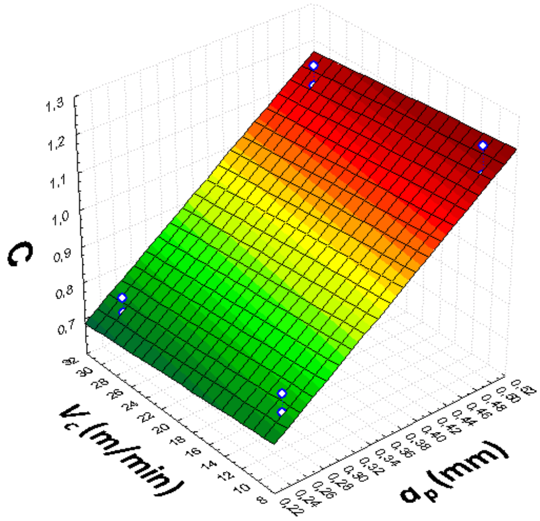

Figure 12. Response surface plot showing the effect of cutting speed and depth of cut for Roundness.

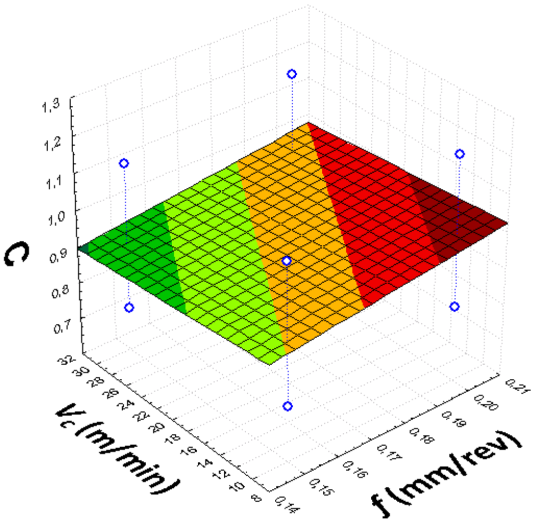

Figure 13. Response surface plot showing the effect of cutting speed and feed rate for Roundness.

The results of roundness are shown in Fig. 11, 12 and 13 for the cutting parameters in the samples studied. As seen from 3D surface graphs the variation of roundness with the cutting conditions is also linear.

Figure 11 show that the depth of cut parameter greatly influences of roundness. In an opposite way, the increase of feed rate results in no influence in the output. Figure 12 reinforces the 3D graph showed in Fig. 11 and also shows that the roundness is almost insensitive to cutting speed. Figure 13 shows that there are no large interference parameters of cutting speed and feed on the roundness.

In addition to the analysis, an attempt has also been made in this research to study the formation of chip. The knowledge of chip forming process is required to understand the accuracy and condition of the machined surface of desired component.

Figure 14 indicates the aspect of chip obtained under dry condition as a function of parameters during machining with chemical vapor deposition diamond (CVDD) cutting insert.

Figure 14. V_c = 30 m/min; f = 0.15 mm/rev and a_p = 0.25 mm.

The chips were obtained throughout the test and demonstrate the effect of cutting conditions. The shorter chips were produced at lower cutting speeds. Further, the chip breaking was seen at both cutting speeds.

5. CONCLUSIONS

The objective of our study was to compare the grinding process to hard turning process applied to cemented carbide samples. The present experimental process deals with the machinability study on 12% Co cemented carbide machining with chemical vapor deposition diamond (CVDD) cutting tool. The interaction effects of cutting speed and feed rate on various aspects of machinability such as arithmetic average surface roughness and the experiments were planned as per full factorial design (FFD) and used as a comparison between grinding and hard turning process. For hard turning process and taking in consideration experimental results, the surface roughness increases with feed rate for any value of cutting speed. Therefore, the surface roughness is highly sensitive to feed rate variations, instead of cylindrical grinding process. However, using adequate parameters was possible to produce samples of 0.18 Ra surface averages.

The roundness results are about 0.72 µm averages. Additionally, the total machining time for a grinding process was 1.5 hours, instead of 0.5 hours for a similar diameter and length using the hard turning process and cutting parameters used. According to the study above, the better combination for surface roughness and roundness was the following parameters: cutting speed 30 m/min; feed rate 0.15 mm/rev and depth of cut 0.25 mm.

Hard turning lathes has many of the same capabilities as cylindrical grinding, but the major benefits of hard turning process were: faster cycle times, four to six times higher stock removal rates, inside and outside features on a single machine using different inserts.

It was possible to conclude that the hard turning of sintered cemented carbide was found more productive than grinding at least for the conditions adopted in the present work.

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