ISSN 2179-3956

FLANK WEAR OF GAS NITRIDED HIGH-SPEED STEEL DURING INTERRUPTED CUTTING OF DUCTILE CAST IRON[1]

Mozart Marcos Marmentini[2]
Giuseppe Pintaúde[3]
Paulo André de Camargo Beltrão[4]

Abstract

In some applications the removal of material in two or more steps is required. A special case is the interrupted cutting, which the drill is subjected to flexural moments. Nitriding can be assessed to increase the hardness and, at the same time, to preserve the bulk properties. This study analyzed the wear reduction promoted by gas nitriding process applied to high-speed steel, in a special case of interrupted cutting of ductile cast iron. A test methodology was developed to simulate an interrupted cutting of ductile cast iron. Three set of drills were tested: as-received high-speed steel (HSS), gas nitrided high-speed steel and a K10 tungsten carbide class. Along tests the average surface roughness of holes were monitored, to support the measurements of flank wear. A detailed characterization of hardness and graphite nodules distribution in ductile cast iron was performed. The flank wear (VB) was reduced in 18% due to the gas nitriding process. Similar VB results for as-received HSS and tungsten carbide drills were observed. However, the wear mechanisms were quite different for each material. For as-received HSS abrasion was predominant, while spalling at the edges were observed for carbide.
Keywords: Interrupted cutting; Drilling; Flank wear; Gas nitriding; Ductile cast iron.

DESGASTE DE FLANCO DE AÇO RÁPIDO NITRETADO A GÁS DURANTE O CORTE INTERROMPIDO DE FERRO FUNDIDO NODULAR

Resumo

Em algumas aplicações a remoção de material em duas ou mais etapas é necessária. Um caso especial é o corte interrompido, no qual a broca está sujeita a momentos fletores. A nitretação pode ser utilizada para aumentar a dureza e, ao mesmo tempo, preservar as propriedades do núcleo. Esse estudo analisou a redução do desgaste promovido pelo processo de nitretação à gás aplicado a um aço rápido, num caso particular de furação interrompida de um ferro fundido nodular. Uma metodologia de ensaio foi desenvolvida para simular o corte interrompido. Três conjuntos de brocas foram ensaiados: aço rápido como-recebido (HSS), aço rápido nitretado à gás e metal duro da classe K10. Ao longo dos ensaios a rugosidade dos furos foi monitorada, para dar apoio às medidas de desgaste de flanco. Uma detalhada caracterização da dureza e da distribuição dos nódulos de grafita do ferro nodular foi realizada. O desgaste de flanco (VB) foi reduzido em 18% com o processo de nitretação à gás. Resultados semelhantes de VB para o aço rápido na condição de como-recebido e o metal duro foram observados. Entretanto, os mecanismos de desgaste foram muito diferetntes para cada um destes materiais. Para o aço rápido a abrasão foi predominante, enquanto que o lascamento nos cantos das brocas foi observado nas ferramentas de metal duro.
Palavras-chave: Corte interrompido: Furação: Desgaste de flanco; Nitretação a gás; Ferro fundido nodular.

1 *Technical contribution to the First International Brazilian Conference on Tribology – TriboBr-2010, November, 24th-26th, 2010, Rio de Janeiro, RJ, Brazil.*
2 *Master in Engineering, mozartmm@yahoo.com*
3 *Dr in Engineering, Academic Department of Mechanics, Laboratory of Surfaces and Contact, Federal University of Technology of Paraná, Curitiba, Brazil, giuseppepintaude@gmail.com*
4 *Ph.D in Engineering, Academic Department of Mechanics, Federal University of Technology of Paraná, Curitiba, Brazil, beltrao@utfpr.edu.br*

ISSN 2179-3956

1 INTRODUCTION

The wear and failure of high speed steel (HSS) drills have technological and economical importance for machining industry. The premature failure of drill point affects the quality of the machined hole. Furthermore, the constant tool changes reduce the availability of the machines, compromising productivity and increasing production costs.(1)

In the constant search for improvement of tools, many investigations have been conducted to develop new and better tools or modify existing tools in order to obtain a longer life for the cutting edge.(2)

The most common materials used in the manufacture of cutting tools are: high speed steel (HSS) and tungsten carbide (WC-Co), each one with its advantages and disadvantages. HSS tools are cheaper and can be made with smaller edge radius, due to its higher toughness. Tungsten carbide can be used at high cutting speeds due to its high resistance, even at temperatures above 600 ºC, but it is more brittle during interrupted cutting than HSS.(2)

In machining operations with interrupted cutting, the contact between the workpiece and the tool is intermittent, causing the oscillation of the loading and temperature increase on cutting tool. Therefore, this kind of process is more sensitive to variation of cutting parameters compared to the continuous cutting.(3-6)

Currently, a trend adopted in the industry to obtain a higher tool life is the use of tungsten carbide, which allows using higher cutting speeds, increasing the productivity. However, under certain conditions of drilling, such as interrupted cutting, the application of carbide tools can not be the most appropriate choice, because this material is semi-brittle and can suffer breakage or chipping. For these specific conditions of machining, high speed steel drills can be an alternative. However, HSS is more sensitive to temperature, presenting a drastic reduction in its hardness above 600 ºC, which accelerates the tool wear by abrasion.

In order to increase the surface hardness and to try keeping it along the reached temperatures at tool surface, nitriding of HSS can be utilized. Some applications in different steels result in increased hardness up to four times (2). The main advantages are the great improvements in wear behavior, increased the corrosion resistance and fatigue also.(7)

Gawroński(8) achieved positive results using gas nitriding to improve the mechanical properties of M2 steel. With the use of appropriate parameters at low pressure nitriding, nitrided surface layers were obtained without pores and brittle nitrides. These characteristics were responsible for the formation of an optimized microstructure and hardness distribution, favorable to application in cutting tools, improving wear resistance.

This investigation aims to test the gas nitriding as a solution for the reduction of tool wear during interrupted cutting of ductile cast iron. The results are compared with the performance of as-received HSS (without nitriding) and tungsten carbide drills.

2 EXPERIMENTAL

The material used to machine was a ductile cast iron, obtained by continuous casting process, produced by Fundição Tupy S.A. Its chemical composition is presented in Table 1.

ISSN 2179-3956

Table 1. Chemical composition of ductile cast iron (in % wt.)

C	Si	Mn	P	S	EC
3.60	2.60	0.23	0.035	0.015	4.47

EC: equivalent carbon

The bars of raw material were supplied in a cylindrical shape with diameter 140 mm and length 100 mm. Each bar was sectioned and in order to characterize the ductile cast iron specimens were extracted from defined positions, as shown in Figure 1.

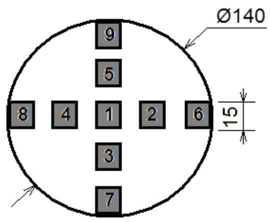

Figure 1. Specimens position for the characterization of ductile cast iron.

As the microstructure varies along the cross-section, a mapping was designed in order to evaluate the metallic matrix, size and amount of graphite nodules. These microstructural characteristics were analyzed in optical microscope, and four images of each position were revealed. In addition, the hardness of ductile cast iron values were determined using Brinell scale. The average values of hardness correspond to a series of five measurements for each position.

M2 twist drills with a diameter of six millimeters, commercially supplied by Irwin Ferramentas do Brasil Ltda, were used as tools, having hardness within 62-65 HRC. The drills have an overall length of 93 mm, 20 degrees helix angle and 118° angle point. Their diameter allows drilling more than 30 mm depth, thus characterizing the deep hole drilling, which has a minimum depth greater than five times the drill diameter.(9)

The drills were surface treated at Oerlikon-Balzers using gas nitriding, following an industrial routine. The nitrided layer was measured, and its average value was 18.8 micrometers, composed basically by diffusion layer. Using nanoindentation testing equipped with a Berkovich indenter (nanoindenter XP-MTS), a hardness of 13 GPa was determined at the surface.

The interrupted cut drilling tests occurred in a Machining Center Arrow 500 from manufacturer Cincinnati Milacron. Fluid lubrication was applied by means of two jet nozzles. The specimens for drilling test consisted in two disks and an intermediate hollow spacer, with diameters of 138 mm, joined by four screws. The upper and lower discs have thicknesses of 20 and 26 mm respectively, and the spacer ring has 18 mm thick. To simulate a special condition of interrupted cutting, the hollow spacer ring has an internal diameter of 108 mm, forming a space between the upper and lower discs. The specimen design is show in Figure 2.

ISSN 2179-3956

Figure 2. Specimens for drilling tests.

The cutting conditions used were: cutting speed 30 m/min, feed 0.135 mm/rev and chip break cycle every 5 mm. We used a drilling specimen for each tool. There were holes with total depths of 50 mm, through hole in the upper disc (20 mm), plus 18 mm spacing without machining and a blind hole in the lower disc with a depth of 14 mm. Thus, the depth of material removal was accomplished by 32 mm drilling, considering the center hole with depth of 2 mm. Altogether; 63 holes in each specimen were made, concentrating them in the middle-radius and center regions. After the drilling, we measured the roughness of the holes: 1, 21, 42 and 63 of specimens. To determine Ra of each hole, the average of three values were used, using four cut-offs of 0.25 mm.

During the tests, six drills were used (one drill for each specimen), identified as follows: drills number 1 and 2 HSS: without gas nitriding, drill 3 and 4: HSS nitrided and drills 5 and 6: tungsten carbide. The tungsten carbide drills of K10 class had the same geometrical characteristics of HSS drills. All the tools were sharpened by Ferramentas Sartori.

We analyzed the flank wear of drills using optical microscopy. The measurement of maximum wear flank (VB_{max}) was made in accord with ISO 3685 Standard.[9] For this purpose, we compared the wear using the image analysis.

3 RESULTS

3.1 Characterization of Ductile Cast Iron

The metallographic analysis allows concluding that different solidification rates gave rise to different microstructures. As expected, the region close to the surface presents the smallest nodules. As the solidification rate is proportional to the cross section bar in the center, through a slower rate of cooling, the diffusion mechanism has occurred for a longer period of time, resulting in graphite with larger diameter.

Figure 2 shows the amount and size of graphite nodules in each region of the bar. The surface region has the highest number of nodules per area (187 nodules / mm²). The regions of the mid-radius and center presented a very close amount of nodules: 130 and 125 nodules / mm², respectively. Thus, an approximately reduction of 49.8% occurred when the analysis is performed from the surface towards the center.

The average size of graphite nodules are 22 micrometers for the surface region. On the other hand, an increase of approximately 31.4% was observed in the mid-radius and center regions, whose values were 26 and 29 micrometers, respectively.

ISSN 2179-3956

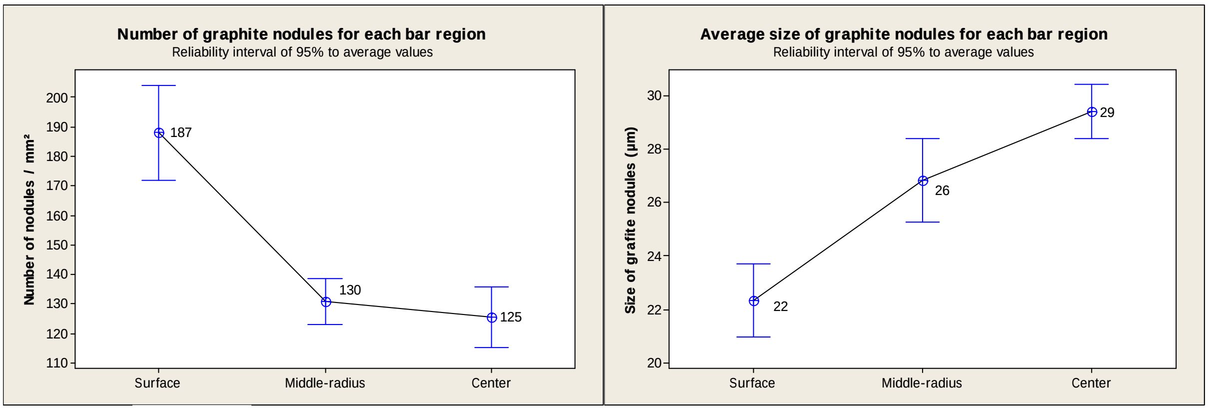

Figure 2. (a) Number of graphite nodules and (b) Mean size of graphite nodules.

The proportion of constituents of metallic matrix and the Brinell hardness of ductile cast iron are presented in Figure 3.

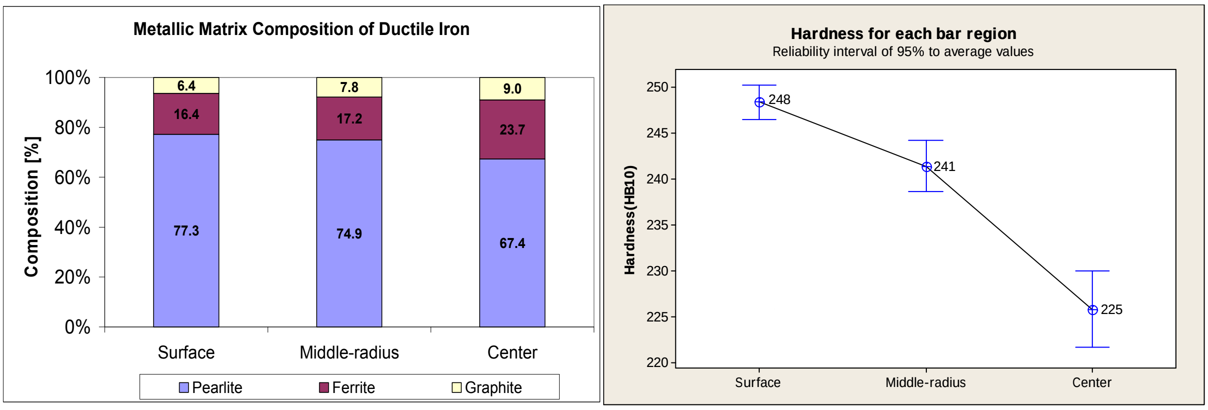

Figure 3. (a) Proportion of constituents of metallic matrix and (b) Average hardness of ductile cast iron as a function of analyzed region.

One can observe in Figure 3a that the center region presents the lowest pearlite fraction (67.4%). The regions of middle-radius and surface present similar values (74.9 and 77.3, respectively). The hardness, showed in figure 3b, is a result of the fraction of microstructural constituents. Especially, the hardness values were proportional to the amount of pearlite. The surface region, which presented the highest fraction of pearlite, is the hardest region (248 HB) also.

3.2 Flank Wear

Figure 4 presents a summary of maximum flank wear (VB max) measured after drilling tests.

ISSN 2179-3956

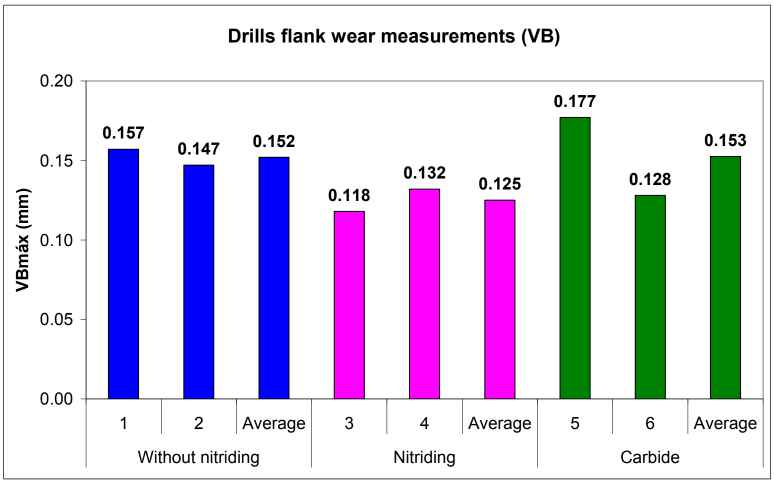

Figure 4. VB maximum values observed in the drills.

The drill 5 made of tungsten carbide showed the highest flank wear VB value (0.177 mm) caused by the corner chipping, as it will be verified further. The drill 1, as-received HSS with no nitriding, presented the second highest value of wear VB with 0.157 mm, caused by the abrasive wear. Tungsten carbide drills showed the highest average wear VB. Finally, it is remarkable that the nitrided drills have the best performance, showing VB of 0.125 mm in average.

HSS drills, both with and without nitriding, showed more stable values of wear, in other words, the variation of flank wear among the drills of the same type was smaller. This can be verified by comparing the amplitude value of VB between HSS and carbide drills, which was 5 times higher for the later.

The wide range of VB within carbide drills was due to lower toughness of them in relation to the HSS. One of the factors may have contributed to this variation was the microstructure of the work-piece material. Each specimen was randomly oriented during their settings. As shown in Figure 3, both hardness and fraction of constituents are different from center to middle-radius region. The tests were performed in both regions, and these variations observed in Figure 3 are enough to affect the wear behavior of drills.

Figure 5 presents some images revealing the flank wear in the tested drills. The wear of HSS drills without gas nitriding was more accentuated in the regions close to the corner and cross edge. The wear mechanism in these regions was predominantly abrasion. Along the edge, small chipping can be found (Figure 5b). Oxidation marks were also observed, because an overheating may be occurred as a consequence of the drill wear (Figure 5a). On the other hand, the nitrided drills showed less intense wear at the corners (Figure 5c). However, they showed more chipping along the edge (Figure 5d). Oxidation marks were not observed in nitrided drills, probably due to less heat in the cutting region. The tungsten carbide drills showed minimum abrasive wear, but excessive chipping along the edge, especially in the corners (Figures 5e and 5f) was observed.

ISSN 2179-3956

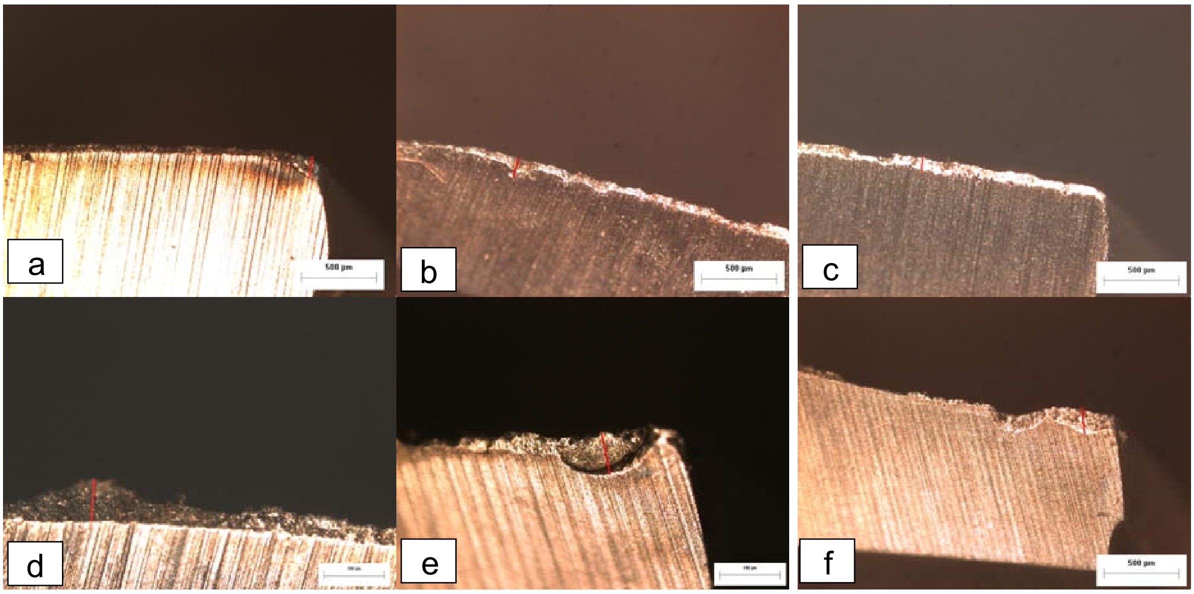

Figure 5. Flank wear observed in drills [a,b] without nitriding, [c,d] nitriding and [e,f] carbide.

3.3 Surface Finishing of Holes

Figure 6 shows the evolution of average surface roughness (Ra) along the length drilled for HSS drills with and without nitriding.

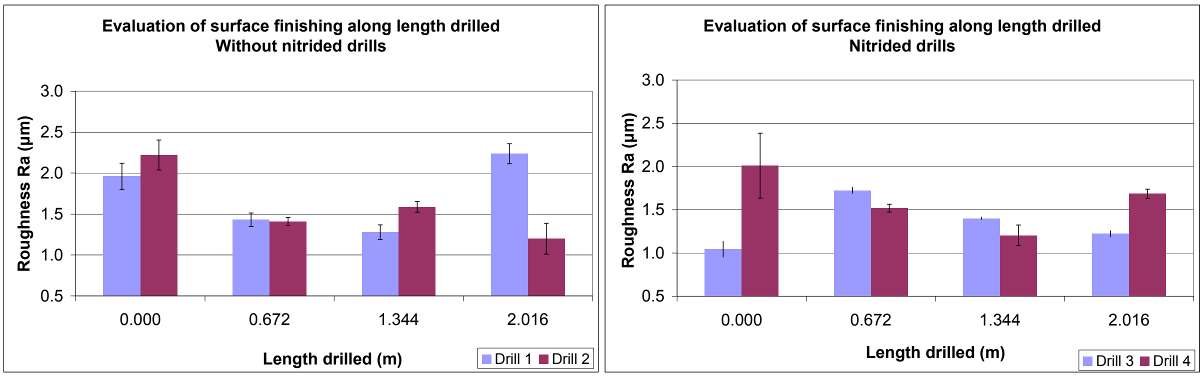

Figure 6. Average surface roughness variation along the length drilled using drill: a) without nitriding and b) nitrided drills.

HSS drills began the operation with about 2 micrometers Ra. After the first step (0.672 m machining), their roughness decreased to 1.5 micrometers. After a few holes drilled, the cutting edge radiuses were more rounded, as a consequence of the initial tool wear. Thus, there was a slight improvement in the surface finishing. The second stage of testing, corresponded to 1.344 m, the roughness remained constant or improved slightly, because the drills were not yet subject to the mild wear. In the last stage of testing (2.016 m), the drills that had higher flank wear (1 and 4) correspond to those subject to the mild wear regime, and the holes suffered an abrupt increase in their surface finish. The drills with minor flank wear (2 and 3), remained under influence only of the initial wear, with further reduction in roughness of machined holes. Figure 7 presents the evolution of surface roughness along the length drilled for carbide drills and comparing the three types of drills.

ISSN 2179-3956

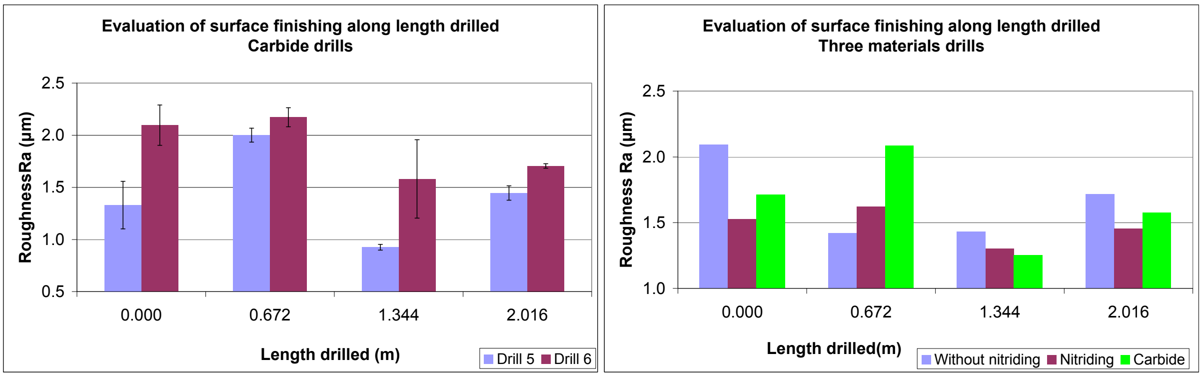

Figure 7. Variation of roughness Ra drilled along the machining length: a) Drills Carbide b) Comparison between the three types of drill.

Figure 7a shows that the initial wear of carbide drills occurred after 0.672 m drilling. As the carbide drills have a higher hardness, the initial wear rate was lower, leading to a later roundness of corner radius occurrence, when compared to HSS drills. When Fig. 7b is analyzed, we can to assert that for 1.344 m only an initial wear for all materials occurred, since a reduction in the surface finish of machined holes was observed. After 1.344 m, both drills were in the mild regime of wear, presenting an increase in their roughness values.

4 CONCLUSIONS

Based on the interrupted cutting tests results performed on ductile cast iron bars using HSS nitrided drills, we can conclude that:

1. HSS nitrided drills showed less wear in relation to those without nitriding and cemented carbide drills. The flank wear after 2.016 m of drilling by nitrided tools was 18% lower.
2. The HSS without nitriding and cemented carbide drills showed the flank wear in the same order of magnitude, but the predominant wear mechanisms were different: abrasion was observed for HSS drills, especially in corners and close to the cross edge, while for the cemented carbide very significant chipping at the corners was observed.
3. HSS nitrided drills presented a uniform and stable wear. On the other hand, cemented carbide showed an unstable wear behavior.
4. Gas nitriding may be used as a solution to interrupted cutting operations.

Acknowledgments

Authors thank to Fundição Tupy S.A. for cast iron supplying; to Oerlikon Balzers Ltd. for the nitriding processing, and to Fersart Ferramentas Ltd. for the drills sharpening.

REFERENCES

1 NICKEL, J.; SHUAIB, A. N.; YILBAS, B. S.; NIZAM, S. M. Evaluation of the wear of plasma-nitrided and TiN-coated HSS drills using conventional and Micro-PIXE techniques. Wear, vol 239, pp. 155 – 167, 2000.

2 MANDL, S.; GUNZEL, R.; RAUSCHENBACH, B.; HILKE, R.; KNOSEL, E.; KUNANZ, K. Characterization of drills implanted with nitrogen plasma immersion ion implantation. Surface and Coating Technology, vol. 103-104, pp. 161-167, 1998.

ISSN 2179-3956

3 KONIG, W; FRITSCH, R. Physically vapour deposited coatings on cermets: performance and wear phenomena in interrupted cutting. Surface and Coating Technology, vol. 68-69, pp. 747-754, 1994.

4 CHANDRASEKARAN, H.; THOORS, H. Tribology in interrupted machining: role of interruption cycle and work material. Wear, vol. 179, pp. 83 -88, 1994.

5 PAVEL, R.; MARINESCU, I.; DEIS, M.; PILLAR, J. Effect of tool wear on surface finish for a case of continuous and interrupted hard turning. Journal of Materials Processing Technology, vol. 170, pp. 341–349, 2005.

6 SAYIT, E.; ASLANTAS, K.; CICEK, A. Tool Wear Mechanism in Interrupted Cutting Conditions. Materials and Manufacturing Processes, vol. 24, pp. 476–483, 2009.

7 LESKOVSEK, V.; PODGORNIK, B.; NOLAN, D. Modelling of residual stress profiles in plasma nitrided tool steel. Materials Characterization, vol. 59, pp. 454-461, 2008.

8 GAWRONSKI, Z. Residual stresses in the surface layer of M2 steel after conventional and low pressure (‘NITROVAC 79’) nitriding processes. Surface and Coatings Technology, vol. 124, pp. 19–24, 2000.

9 ISO 3685:1993, Tool-life testing with single-point turning tools. In: TC 29 Small tools.