EVALUATION OF THE WEAR HSS TWIST-DRILLS WITH DIFFERENT TREATMENTS SURFACES IN THE DRILLING PROCESS OF CAST IRON

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Abstract. *The drill faiulures caused by wear and/or fracture has always been motive for worries in drilling operations because of the need of stopping the process for sharpening or tool changes, representing addicional costs and loss of productivity. Thus, studies about faiulure types and mechanisms in drills as way the aplication evaluation of different protective coatings must be considered. The development of this coating made it possible the use of drills in hard-cutting situations, because when apllied in correct use, increases the superficial hardness, and under high-temperature, minimize the abrasive wear caused by the decreasing of coefficient of friction between tool and workpiece. This study allows a substancial increasing in the cutting speed and tool-life. If compared with the others surface superficial treatment processes, the plasma nitriding is a very viable alternative for superficial hardening in high-speed steel (HSS) drills. Thus, the paper proposes evaluate the performance of four HSS twist-drills AISI M2 with diferent surface modification: plasma nitrided, without coating, cobalt coating, and titanium-nitride coating, all of them tested in a blank of cast iron type G3000 with 200 Brinell hardness. The plasma nitriding was realized in 400^{o}C of temperature. The application of plasma nitriding presented a wear reduction and consequently a twist-drill lifetime increasing associated with the other drills tested.*

Keywords*: HSS twist-drills AISI M2, plasma nitriding, drilling process, tool-wear*

1. INTRODUCTION

The majority parts of any type of industry have at least a hole, and only a small portion of those parts comes with the ready hole of the obtained workpiece process (foundry, forging, etc.). In drilling, a high speed steel (HSS) twist-drills is the most used tool due to this low cost. In spite of this name, the used cutting speeds are very low in compared with more modern tool materials. Considering the existence of more advanced tool materials than HSS, the application of these materials in several machining processes is restricted because the tool geometries, cutting conditions or machine tools. Much of the used machine tool in manufacturing industries does not apply the necessary cutting speeds for carbide drills. Therefore, the HSS drills still used extensively. However, some HSS properties as wear resistance and coefficient of friction are not consistent with the cutting efficiency desired (Diniz *et al*. 2003).

Drilling is one of the mechanical machining processes more used in the manufacturing industry which aims open holes, expand holes or create finishing holes in parts. Holes can be generated in dimensions that vary from few millimeters to several centimeters of diameter with aid of a multiple-edges tool. For this, tool or workpiece moves according a rectilinear trajectory, coincident or parallel to the main machine tool axis, as illustrated in Fig. (1) (Ferraresi 1977, Heraldo 2003).

Due to the low cost of HSS tools, most companies still use this twist-drill type in drilling of steels classified as difficult machinability. The high-speed steel AISI M2 is a steel-alloy molybdenum-tungsten that has an excellent combination of toughness and abrasion resistance, also excellent hot hardness, being one of the materials most used for roughing and finishing tools (Heraldo 2003).

The twist-drill is the most manufactured and widespread tool for machining. The drilling process with this tool involves from 20 to 25% of the total applications in machining, be in the generation of shallow or deep holes, in the solid or with pre-hole drilling (Rubenstein 1991). As tool, this is normalized by ABNT NB 205 (1989) according with their constructive and geometric characteristics as well as its application in the machining of the materials.

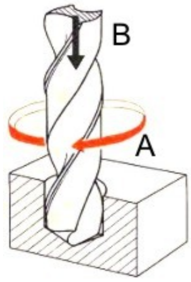


Figure 1. Drill movements in hole-making: A) cutting in rotation; B) feed in translation

In the drilling processes, the same way as in general machining, the lack of rigidity of the machine tool and/or the fixation device, the loss of sharpness of the tool cutting edge, among other factors, directly influence the final part quality and consequently causing dimensional and form deviations (Agostinho *et al*. 1995, Novaski 1996). In general, the degree of expected accuracy (work quality) in drilling processes is IT 10 or IT 11, with values of roughness Ra (arithmetic average) from 1.6 to 6.3 µm (Ferraresi 1977). This degree of accuracy can be improved or worsened, depending on cutting conditions and equipments used.

The problems of wear in cutting tools have always been of concern due to the need to stop the process to tool change, meaning additional costs and productivity loss. Wear is defined as the destruction of one or both surfaces that composes a tribological system, usually involving progressive loss of material (Hutchings 1996). Thus, studies on the formation mechanisms and types of wear that occur in drills, as well as evaluating the application of different coatings or surface treatments should be considered.

The development of coatings allowed the use of tools in severe situations of cut (high-speed machining and dry cutting) as, correctly applied, increase the superficial hardness of the tool, and under high temperature conditions, minimize the effect of abrasive wear by reduction the coefficient of friction between the tool and the workpiece (Heraldo 2003). The coatings act in two important ways: as thermal barrier between the workpiece and tool, reducing inflow heat to the tool substrate, and as a lubricating layer, reducing the coefficient of friction at the interface chip/ tool/ workpiece and also acting in the reduction of the adhesion process (Miranda 2003).

The techniques of deposition of coatings for steel are numerous. The coatings are used for different purposes, such as: finishing surface, protection against oxidation, hardening of the surface or increased wear resistance (CIMM 2009).

In recent years, the use of HSS twist-drills with hard coatings (TiN, TiAlN) has increased. It is usually obtained by physical vapor deposition (PVD) and gives an increase in wear resistance due to high surface hardness and a reduction in the coefficient of friction in the tool/ workpiece and chip/ tool interfaces. These coatings have enabled a substantial increase in cutting speed and tool-life (Heraldo 2003).

An increase in the content of alloy elements in HSS twist-drills also allows an increase in wear resistance and therefore enhance in tool-life; however, the manufacture of this material becomes more difficult and, consequently, creates an increase in production costs. Cobalt is an alloying element that raises the hot sensitization temperature, increases the hot hardness and enables better carbides solubility (Novaski 1996). Another important alternative is the plasma nitriding. It is particularly suitable for obtaining the desired characteristics of superficial hardening in HSS M2 drills, since the alloying elements are strongly nitrides formers (Figueroa and Zagonel 2005, Wanke 2003).

The plasma (or ionic) nitriding is a thermo-chemical treatment process that consists of diffusing the atomic nitrogen on the ferrous and non-ferrous alloys surface (Edenhofer 1974) through a chamber vacuum nitriding. The high surface hardness obtained is due to the formation of nitrides and carbonitrides in surface areas of the substrate (diffusion zone), finely dispersed in the precipitate form, which distort reticulated (Kieckow et al. 2006, Zlatanovic 1991). The amount, the nitrides type and distribution of alloy formed and the material base hardness determine the hardness observed in the nitriding layer (Kieckow 2008). The component fatigue resistance can also be significantly increased (Bell *et al*. 1998).

Several factors and process parameters influencing the formation and microhardness of the nitrided layer, the main ones are: time, temperature, concentration of alloy element nitriding formers (W, Mo, Cr, V, Ti and Al) in the substrate, microstructure, part dimension and geometry, work pressure, mixture composition of the working gas (N_2/H_2) and electric tension and current (Béjar and Vranjican 1992, Bougdira *et al*. 1991, Fancey *et al*. 1995, Pessin *et al*. 1997, Pessin *et al*. 2000, Rocha 2000 and Tier 1998).

Due to no need tempering in the process and the low temperature used (between 350 ºC and 550 ºC), the plasma nitriding produces less distortions and deformations than other thermo-chemical processes of hardening.

More than ever it has carefully investigated the performance of the cutting tool in order to potentially extend the tool-life and improve the quality of the machined part. Moreover, it hopes to obtain a certain reliability degree in its service work. Like this, the objective of this study is to evaluate the lifetime of AISI M2 twist-drills plasma nitrided and with other types of superficial treatments for the machining of gray cast iron blanks. The tool-life criteria were evaluated from the number of holes. During the experimental tests, the process parameters (drill geometry, material machined and cutting conditions) are kept constant.

2. EXPERIMENTAL PROCEDURES

In the drilling process of gray cast iron with HSS twist-drill, it aims to evaluate the performance of plasma nitrided tools in comparison with other three tools with different modification types. For that, they will be described in the subsequent items (1) the methodology used in the treatment of plasma nitriding, (2) the comparative tests of drilling carried out and (3) the sequence used to measure the wear of twist-drills.

2.1. Plasma Nitriding Process

The plasma nitriding process was accomplished in the LABORATORY OF SURFACES ENGINEERING (LES) of the Industrial Mechanics Engineering course (EIM) at URI – Campus de Santo Angelo.

Twist-drills HSS AISI M2 with nominal chemical composition (80.7% Fe, 6% W, 5% Mo, 4% Cr, 2% V, 0.8% C, 0.7% Co, 0.4% Mn and 0.4% Si) with 10 mm diameter, 80 mm cutting length and cylindrical rod (for fixing in male chuck) were nitrided. The cleaning was performed with ultrasound in acetone liquid environment for 15 minutes. The samples were placed into the vacuum reactor to a base pressure of 1.0 Pa. After high pressure up to 100 Pa and ionized argon (Ar) gas, cleaning was made by ionic bombardment of the samples at a temperature of 150 ºC for 30 minutes.

The system used for the plasma nitriding consists of: a source of electrical DC pulsed tension with output up to 800 V and 2 A, a vacuum reactor of stainless steel of 0.05 m^3 with control of input gas, a pressure sensor, and a temperature sensor.

Figure (2a) shows a photo of the equipments used in the process; Fig. (2b) shows a photo of the vacuum reactor; Fig (2c) a photo of the plasma nitriding process details and used temperature measurement instrumentation. The twist-drills were centralized in the sample holder at a halfway distance from the borders. Plasma color is a typical gas mixture of nitrogen (N_2) and hydrogen (H_2). Type J thermocouples were inserted at the top of device (where the twist-drill was) and at the bottom of the support.

(a) (b) (c)

Figure 2. (a) Equipments for twist-drills plasma nitriding. (b) Plasma nitriding reactor in operation. (c) Details of instrumentation

The gas mixture for the plasma nitriding (25% of N_2 in balance with H_2) was introduced into the reactor only after the work temperature of 400ºC was reached. Heating was by the ionic bombardment with Ar. The process temperature was maintained at 400 ºC for 30 minutes. The working pressure was 700 Pa. The cooling was made inside the reactor at the base pressure. Table (1) summarizes the adopted parameters in the process of nitriding twist-drills.

A plasma nitriding of 30 minutes was chosen because previous works demonstrated good results for the HSS AISI M2 steel. The work of Kieckow *et al*. (2006) showed that in the Rockwell C indentation tests, the duplex system with TiAlN, nitrided at 400 ºC showed better results as to support the load of the film (mechanical collapse) than nitrided at 450 ºC. Under duplex treatment with TiN, Shengli *et al*. (2001) showed that the adhesion of TiN H13 steel plasma nitrided, with formation only diffusion layer, gradually increases until 1 hour of process. After that, there was loss of the film adhesion. Sato *et al*. (2003) achieved a greater number in holes in drills submitted to the duplex system TiN/HSS, for those nitrided for 30 minutes at 450 ºC. Franco Jr. (2003) investigated the duplex system TiN/AISI D2; he obtained larger adhesion to short nitriding times (approximately 42 minutes). Finally, Kwietniwski *et al*. (2004) achieved good results in the duplex system TiN/AISI M2 nitriding the substrate for 30 minutes at 400 ºC.

Considering a similar situation to this latter work, where the tool has sharp edges and, therefore, may present fragile edges, chosen here to work the process at low temperatures and short times of nitriding.

Table 1. Parameters adopted in plasma nitriding process

Process parameters	Drill A
1. Time	30 min
2. Temperature	400°C
3. Material	HSS AISI M2
4. Geometry	Twist with ∅10 mm and L = 80mm
5. Pressure	700 Pa
6. Mixture of work gas	25% N_2 + 75% H_2
7. Electric voltage	710 V
8. Electric current	910 mA
9. Work factor	0.5

2.2. Drilling process

In the design of experiments, cutting operations were performed at FUNDIMISA – CASTING & MACHINING Ltd. Company in a MAZAK VTC 220C machining center with three work axes, nominal power of 25 CV, maximum spindle speed of 5000 rpm, ATC (automatic tool changer) and magazine for 30 tools, as illustrated in Fig. (3).

Figure 3. Machining Centre MAZAK VTC 220C

Table (2) indicates the cutting parameters adopted in drilling tests based on operational conditions applied by the FUNDIMISA and recommended by the drills manufacturer.

Table 2. Cutting parameters for tool-wear evaluation in drilling operations

n [rpm]	$\mathbf{v_c}$ [m/min]	**f** [mm/rev]
630	20	0.14

From the manufacturer, for cutting parameters adopted, the useful life of HSS twist-drill is estimated at 132 holes; after that, it should be made the sharpening of this. The workpiece used in drilling tests was obtained from a blank of gray cast iron G3000 with hardness of 200 HV and thickness 48 mm, which was previously machined in order to homogenize the surface conditions for the tests, so as not to mask the results. Figure (4) presents a photo of the specimen used, which were made all the holes. The tests were divided according to the following classification: (a) HSS without treatment; (b) HSS plasma nitrided at 400°C; (c) HSS cobalt; (d) HSS with TiN coating.

According to Ferraresi (1977), cast irons can be machined with or without emulsified oils for lubricate and cool. In drilling operations, the cutting fluids act to reduce friction and vibration, reducing the generation of thermal energy and cooling the pair drill/hole friction. This work utilized a ROCOL ULTRACUT 370, long-life soluble oil applied at a dilution among 20:1 and 40:1.

In the drilling tests to verify the flank wear behavior, the evaluation of the twist-drills was made according to the criterion of machinability of tool-life. It was previously defined as the criterion for end of life would be evaluated in function of the wear behavior observed in HSS twist-drill without treatment, with reference to the number of holes specified by the manufacturer (132 holes for the cutting parameters adopted and work material above cited). However, all of the tests were interrupted with 100 holes in function of HSS twist-drill breakage without treatment in this amount of holes, characterizing the end of tool-life. In all twist-drills were measured the average width of the flank wear (VB) of the two main cutting edges and also the wear (decrease) in the transverse cutting edge from digital images acquired every 20 holes made. It is noteworthy that all drilling cutting conditions were kept constant during the tests.

Figure 4. Workpiece used in drilling operations for tool-wear evaluation

2.3. Acquisition of tool-wear image

The images of two main cutting edges and also the transverse cutting edge of each twist-drill were purchased *in loco* (FUNDIMISA) through a system composed by a digital camera NIKON COOLPIX 4500 µm coupled to a STERIOSCOPIC PANTEC, as Fig. (5). The captured images were magnified 20 times. This sequence was required to verify and record graphically the tool-wear evolution of each twist-drill tested.

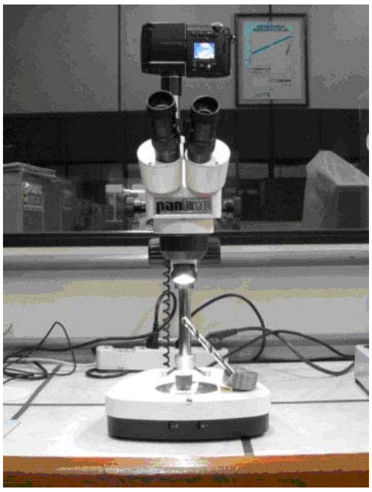


Figure 5. Digital image acquisition system for tool-wear detection through the drilling operations

To make sure that the position of the clearance surface (flank) was perpendicular to the axis of the stereoscope lens, a device of steel was built aiming for the correct and repetitive twist-drill positioning to obtain a plane surface for pictures in focus. The device was fixed to the base of the stereoscope. Figure (6) illustrates its format. An indentation made with the durometer in the device (indicated by the arrow) served as reference for alignment with another indentation in the twist-drill, ensuring proper positioning to capture the image.

Preliminary tests showed that with the evolution of the tool-wear, it changes the main cutting edge drill geometry, making it difficult to obtain a reference point for its measurement. For this reason, in setting the wear value, after accomplishing the sequence of the 20 holes, it was made a comparative analysis between the surface images of the drill without wear with the image of the drill with wear, *id est.*, a measurement template based on "new" drill was superposed on the images of the "worn" drills. It is noteworthy that each cutting edge of the twist-drills had its own template comparison, and this can be observed the location of points where the tool-wear measurements were made, as highlighted in Fig. (7).

The measurement of drill-wear was done in the LABORATORY OF MECHANICAL AND MATERIAL TESTS (LEMM) at EIM-URI with the aid of MOTIC IMAGES PLUS 2.0 software from the analysis of the acquired digital images during the drilling tests performed at FUNDIMISA. Once the wear is more pronounced at the ends of the twist-drill (higher cutting speed), the wear was measured in three points indicated in the Fig. (7b) of each cutting edge and recorded the average of these values. The value of VB was determined from that average.

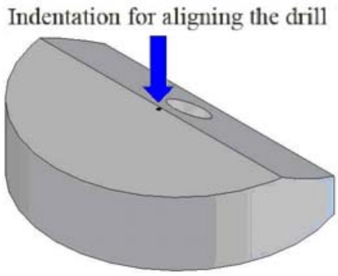
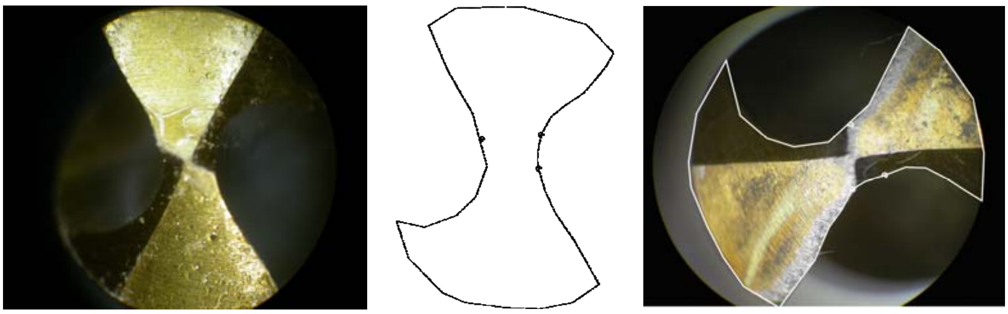


Figure 6. Tool-support scheme for positioning of twist-drills for image acquisition

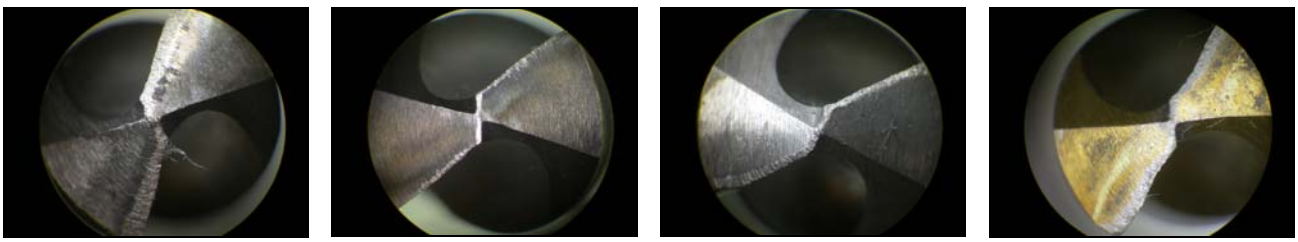


(a) (b) (c)

Figure 7. Photos of TiN coated HSS twist-drill: (a) new cutting edge; (b) template of cutting edge; (c) failure cutting edge with template

3. RESULTS AND DISCUSSIONS

Figure (8) exhibits photos of the front part of the tested twist-drills, showing the wear in the main and transversal cutting tool edges after the execution of 100 holes. The images show the extent of wear in twist-drills: Fig. (8a), the wear was more severe (breaking in the orifice number 110); Fig. (8b), the wear was the smallest of all, indicating the efficiency of the process by increasing the tool-life in test conditions; Fig. (8c), it was perceived a more accentuated wear more on the cutting edge; Fig. (8d), the wear was more pronounced in the intermediate region of the flank.



(a) (b) (c) (d)

Figure 8. Photos of the main cutting edge of twist-drills after 100 holes: (a) HSS without coating; (b) HSS nitrided at 400°C; (c) HSS cobalt; (d) HSS TiN coating

The VB wear values quantified to each 20 holes in each twist-drill tested were presented in the form of graphic curves of Fig. (9). These curves show the evolution of the wear in function of the number of holes realized for each twist-drill illustrated in Fig. (8), *id est.*, the wear rate of each twist-drill.

It is possible to see similarities in the initial behavior of the wear of twist-drills until the 20^{th} hole for the graph of Fig. (9). All had a higher wear rate in those early holes. However, the nitrided sample was less susceptible to wear in this range of holes. After the 20th hole, the tendency was to keep each twist-drill a wear rate approximately constant until the 80th hole. The slopes of the curves were similar. The twist-drills coated with TiN and nitrided at 400ºC maintained a wear average in each measurement space. However, the wear rate of nitrided twist-drill was even lower, because the curve is less steep than the twist-drill coated with TiN. The nitrided sample was less sensitive to wear over full of holes. There are indications of micro-chipping fractures for the smallest toughness of the cutting edge. The HSS cobalt twist-drill presented a different behavior of the wear curve, tending to decrease their rate after the 80th hole, which was expected by the higher hot hardness and lower toughness in terms of tool carbides. Since HSS twist-drill common, the wear rate was accentuated after the half life of the twist-drill, from about the 60th hole; Fig. (8a) showed the wear of that twist-drill, apparently abrasive.

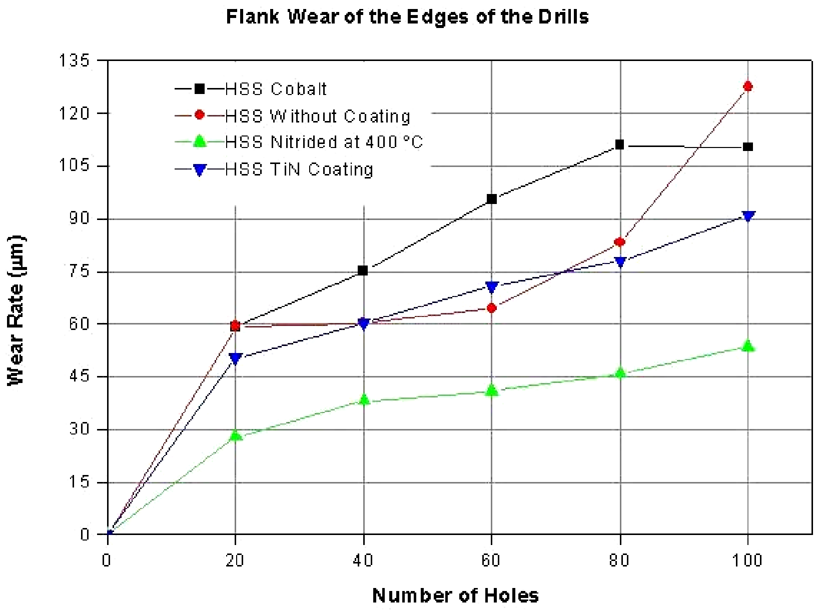


Figure 9. Comparative graph of the flank wear behavior of twist-drill cutting edges

The results show that the plasma nitriding process can improve the tool-life, compared with other coating procedures used in this work. Associated with the tool-life, comes a series of other factors that are directly related to production costs, as the number of holes, the decrease in downtime, increased productivity etc.

The cost of HSS twist-drills coated with TiN and cobalt is respectively 20% and 100% higher than conventional HSS tools (without treatment). Thus, it is necessary to consider whether it is possible to nitride at a lower cost and achieve better performance with the tool.

4. CONCLUSIONS

In general, it can conclude that the HSS twist-drill uncoated and HSS cobalt coated employed in drilling process of gray cast iron G3000 for the cutting parameters of this study showed a lower performance of twist-drills coated with TiN and plasma nitrided.

The tests showed that in machining of gray cast iron with cutting fluid, the plasma nitrided twist-drills still presented better behavior than those coated with TiN. These results indicate that the parameters of the plasma nitriding process adopted in this research for the machined material were adequate.

Obtaining a lower wear rate in the machining involves a longer tool-life, a greater quantity of drilled parts, a less downtime for tool sharpening or replace, and a greater productivity. This corresponds to an increase in profitability by reducing these costs.

Besides these mentioned factors, the cobalt and coated with TiN HSS twist-drills have a cost higher than the plasma nitrided twist-drills. That is, the plasma nitriding process can provide a better tool with a lower cost.

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