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Experimental study of tapping wear mechanisms on nodular cast iron

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Abstract

Tapping by cutting is one of the most common operations in manufacturing. This multi-teeth tool, known as a tap, cuts the thread in a hole when the piece has a high added value. The thread quality is ensured when the tap is new or slightly worn, yet when tap wear is high; the quality of profiles exceeds tolerance limits and therefore a defect occurs in the manufacturing line.

The aim of this paper is to study the tap wear of titanium nitride coated taps measured on nodular cast iron. The level of tap wear is determined by optical images and the wear mechanics are classified by scanning images and energy dispersion spectroscopy analysis. The results highlight that the critical part in measured taps is between the last chamfer and the first cylinder teeth and, consequently, the thread profile is under-sized. Beside adhesive wear, coating removal and chipping are the main wear aspects during tapping operations.

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Keywords: GGG50, HSS, quality, wear, thread;

1. Introduction

Tapping is a widely used machining process for internal thread mating. It consists of cutting internal threads on the wall of a hole by means of a tool called a tap that has cutting edges on its chamfered periphery. It is a difficult

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operation owing to the difficulty of keeping synchronism between the rotation and the feed movements of the tap especially at high speeds [1].

Tapping is usually performed at the end of the product flow, when the work piece has reached its maximum added value. To understand this process at high speed, it is necessary to notice the wear in the taps after the appearing of the first thread defect.

Wear deteriorates the sharpness of the teeth cutting edges and as a result the cutting process demands more energy and therefore produces more heat. With more heat the teeth soften, wear accelerates and teeth tips become prone to chipping. The clearance faces get progressively loaded with welded work piece material, and as a result the quality of the tapped thread flanks worsens, the major diameter of the threads diminishes, thus producing unacceptable threads.

Although the bibliography is scarce in relation to wear in tapping operations and more abundant in other manufacturing processes, this paper tries to include all of them.

The main wear mechanisms of HSS cutting tools are abrasive and adhesive wear, plastic deformation, fatigue and fracture and coating removal, which perform the crater wear in the rake face, edge chipping, notch wear and wear in the clearance faces [2]. Other studies emphasize adhesion, abrasive and plastic deformation mechanisms when tapping grey cast iron at high speed [3-4]. Beside, another study proposes tapping operation in hardened steels and abrasion, adhesion and worn edge are main wear aspects [5]. Since the wear is critical in tapping operation, some researchers propose some investigations on wear tool with coating taps and other work materials [6-7], the results are similar.

The aim of this paper is to know and understand the main wear mechanisms in TiN coated HSS tapping operations at high speed after the thread is out of tolerance range. In this study, the lack of quality is due to the fact that the thread is under-sized. Firstly, the set-up of measurements is presented and the results are analyzed, secondly, a wear study is proposed by optical and SEM images to identify the main wear mechanisms. Finally, to confirm the wear mechanisms an EDS analysis is performed to corroborate each kind of wear.

Nomenclature

TiN	Titanium Nitride
SEM	Scanning Electron Microscope
EDS	Energy Dispersion Spectroscopy
HSS	High Speed Steel
IM	Image Manager
CNC	Computer Numerical Control

2. Experimental procedure and results

The experiments are conducted on a vertical machine tool (Kondia B500). Tapping tests were performed at high speed (65m/min) and in dry conditions using a set of 4 identical HSS taps of 10mm in diameter, 1.5mm pitch and TiN coated (from Tivoly Groupe). Tap chamfer angle was 9º and the taper length was about 6.5mm equivalent to 4-4.5 threads, as it can be seen in Figure 1a & 1b.

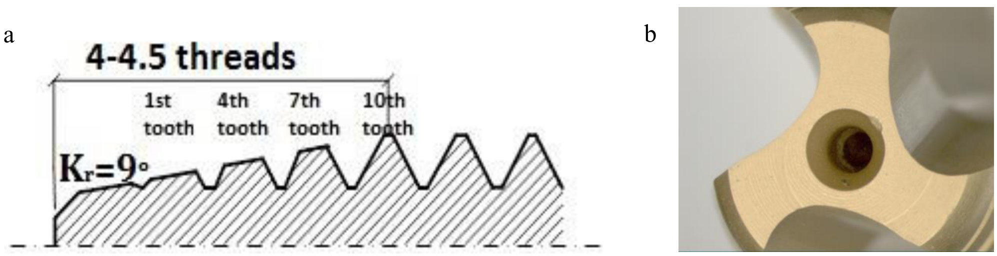

Fig. 1. (a) HSS M10x1.5 tap geometry; (b) TiN coated tap of three flutes.

The work piece material was a GGG50 ductile nodular cast iron in 20mm thick plate format. Before tapping, holes of 8.5mm diameter were drilled with HSS drills. All the previous holes were measured with a micrometer at three levels (entrance, intermediate and exit) previous to the tapping operation to check that they were in tolerance.

-Table 1. Tool life (number of thread).

Tap	Tap life (threads)
1	60
2	68
3	70
4	62

Table 1 shows the tool life of the four taps. The tap quality is correct when the tapped holes passed the "go-no-go" gauge test (quality H6). The lives are similar yet they are low due to high speed and dry conditions.

3. Wear study in the teeth and results

To observe the main wear in clearance and rake faces, optical microscope (LEICA DC 300) has been used, see Figure 2a. The calibration of microscope was made according to a pattern given by Leica. Besides, a wear parameter is measured by the Leica IM software to know the wear level per tooth in each tap. For an observation in detail, as well as for the identification of the wear mechanics of worn teeth which cut threads, an EDS analysis by a SEM has been employed. The taps have similar wear behavior since they are from the same batch and are tested with the same cutting conditions.

3.1. Optical images

Wear is measured quantitatively by a parameter called relative wear %A, the %A parameter is defined:

$$\%A = \frac{A_{sp}}{A_p} \cdot 100 \quad (1)$$

where A_p is the area of clearance face on each tooth along 1mm length of thread and A_{sp} is the wear area of clearance face in A_p (see Figure 2b). Both are calculated by the Leica IM software.

a

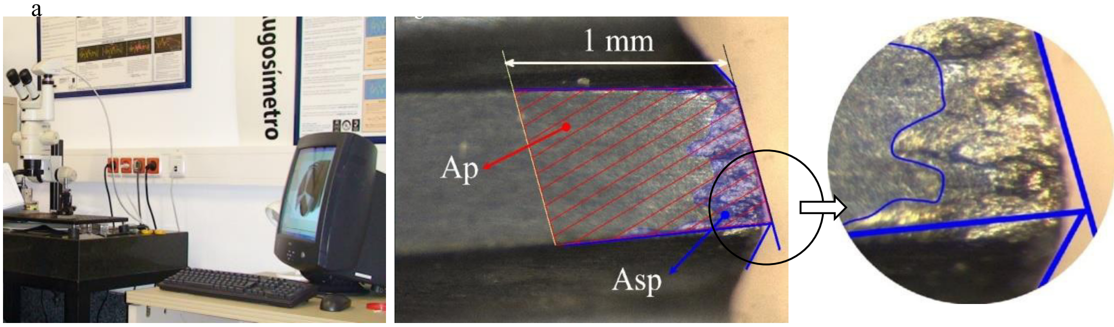

Fig. 2. (a) Leica microscope; (b) Wear (A_{sp}); control (A_p) areas in the clearance face

Figure 3 represents the *%A* parameter along the teeth of each tap. The wear profiles of all taps are similar. The first three teeth have a low level of wear, then the wear is incremented (15%) between the third and fourth tooth and this level is kept until the sixth tooth. From the seventh tooth, the wear level increases quickly until the maximum is reached in the 11th or 12th tooth depending on the tap. The maximum average of all taps is 90%. The wear decreases gradually and in the 18th tooth has the same level as the first tooth.

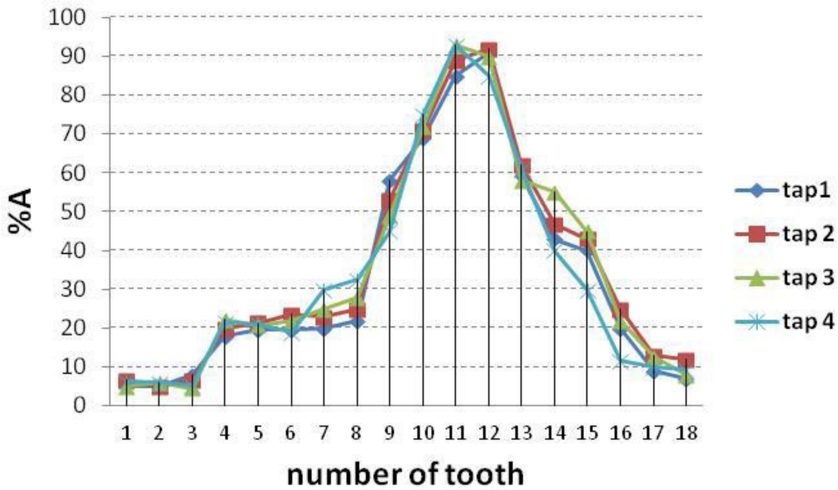

Fig. 3. Evolution of *%A* on the teeth of taps

This graph indicates that the last chamfer teeth and the first cylinder teeth of a tap (see Figure 1) are the critical points. These last chamfer and first cylinder teeth are in a charge of sculpting the thread profile and keeping the tolerances, respectively. In this case the lack of quality is when the threads are under-sized. Therefore, the high wear levels are on the 11th and 12th teeth.

To illustrate the wear in detail, two images from new and worn taps are joined in Figure 4. The reason why the tapped threads become unacceptable (when the go gauge is unable to go) is always that the tapped threads major diameters are smaller than the dimensional tolerance permits because the wear of the tap teeth makes the main edges of all active teeth recede.

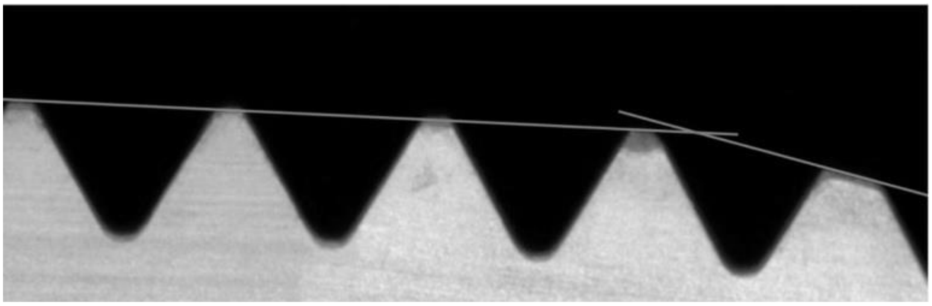

Fig. 4. Lack of quality: new and worn tap profiles.

3.2. SEM images and EDS analysis

Before illustrating the tap wear with EDS analysis, Table 2 shows the chemical composition of HSS and GGG50, respectively.

Table 2. Chemical composition of high speed steel (HSS) and nodular cast iron (GGG50).

Material	Fe (%)	C (%)	Cr (%)	Mo (%)	W (%)	V (%)	Si (%)	Mn (%)	P (%)	S (%)	Cu (%)	Mg (%)	Ni (%)
HSS	80.7	1.30	4	5	6	3	-	-	-	-	-	-	-
GGG50	93.4	3.71	0.02	-	-	-	2.44	0.18	0.034	0.001	0.21	0.037	0.02

Figure 5 illustrates the adhesive wear on the clearance face of the 11th tooth and EDS analysis confirms the existence of adhesion owing to appearing Si or Mn from work-piece material on clearance face. These last chamfer teeth have to remove the work-piece material that the previous chamfer teeth have not eliminated it. The heat between tooth and piece increases and, consequently, adhesion mechanism appears.

a b

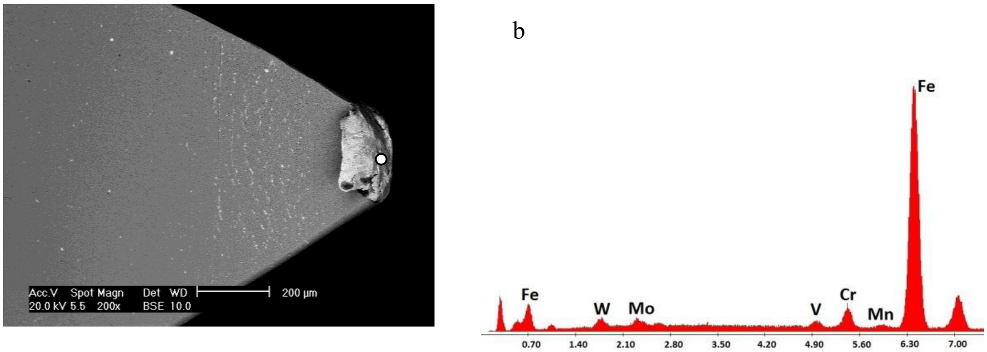

Fig. 5. (a) The adhesion on the clearance face; (b) EDS analysis in the white point.

Figure 5b shows the existence of vanadium on the clearance face. This is evidence of coating removal that will be described below.

Not only is the adhesion mechanism on the clearance face but it also appears on the rake face as it is observed in Figure 6a. For more detail, see Figure 6b.

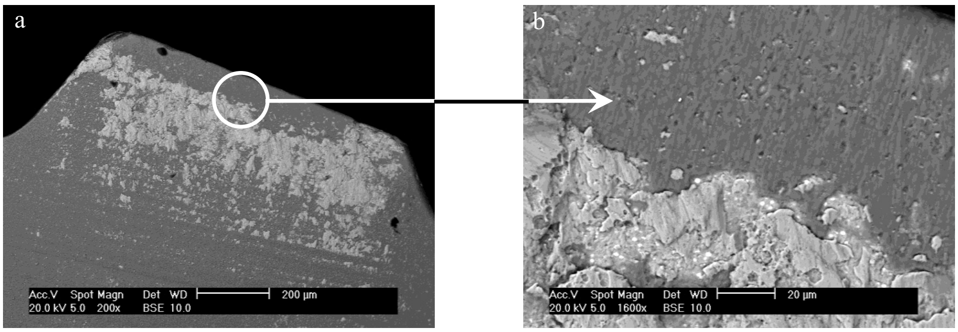

Fig. 6. (a) The adhesion on the rake face; (b) this adhesion in more detail.

Coating removal is shown in Figure 7a. There are two lines (number 1 and 2 in the Figure 7b); the first line separates the TiN coating and the coating removal layers and the second line separates the coating removal and micro-welded layers. These layers diminish in height due to micro-chipping. The micro-welding material from work-pieces, when a thread is mating at high speed, is welded on TiN coating and then, when the tool is tapping the next thread, the cutting forces remove the welded material and the TiN coating together. Consequently, the substrate appears.

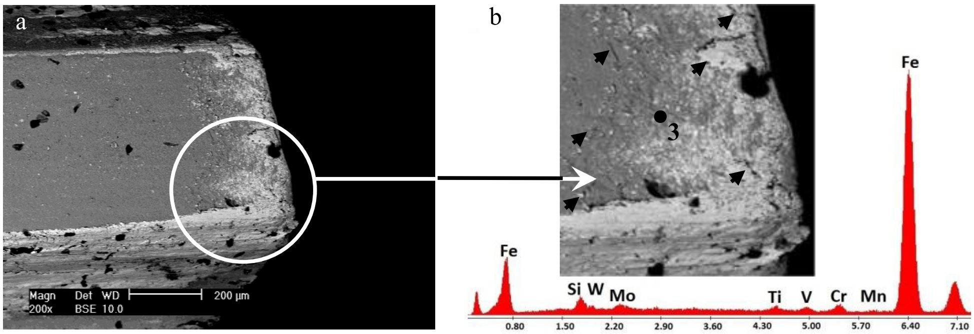

Fig. 7. (a) Coating removal on the clearance face; (b) this coating removal in more detail and EDS analysis in the black point.

The EDS analysis in a black point (number 3) of clearance face corroborates the existence of micro-chipping and coating removal as Mo, V and W are in the Figure 7b and they are the components of substrate (see Table 2).

Figures 8a and 8b show the edge chipping in the 10th tooth. This great crater transforms this active tooth into inactive. Thus, the following teeth have to remove the material that this tooth has not removed.

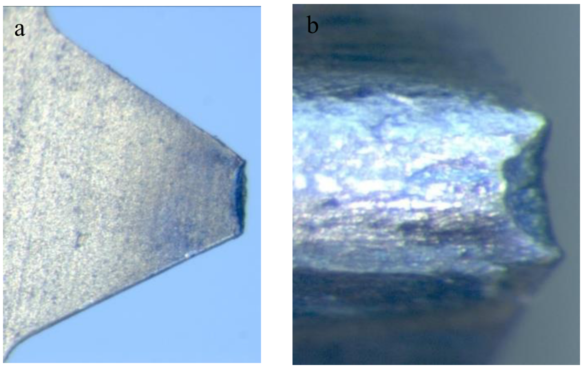

Fig. 8. Edge chipping shown from (a) the rake face; (b) the clearance face, 5x image and 10x image, respectively.

These following teeth (11th, 12th, etc) present a shape, when they are new, closer to the thread profile since they are designed to calibrate the thread and not to remove work-piece material. Thus, the wear is propagated through the cylinder teeth (see Figure 4) generating a lack of thread quality, that is, the height of it is out of tolerance range and, therefore, the head of go gauge does not enter into the thread.

4. Conclusions

The optical and SEM images of measurements of M10x1.5mm threads machined with TiN coated HSS taps conducted in a vertical CNC machine at high speed in cast iron GGG50 have demonstrated the wear propagation through the cylinder teeth which reduces the height of the thread and, therefore, a defect occurs in a manufacturing line.

The teeth (10th to 12th) between the chamfer and cylinder part of the taps have a high level of wear on the clearance face (*%A*) and present a reduction in the height. This part of the tap is critical at high speed.

EDS analysis on different teeth of taps have demonstrated the existence of adhesion in the rake and clearance faces, the coating removal due to micro chipping on the clearance faces and chipping in the chamfer tooth edge which provokes the wear propagation to the following teeth.

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