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PERFORMANCE OF THE TOOL FOR TAPPING WITH AND WITHOUT TRIBOLOGICAL COATING IN MACHINING OF CRANKSHAFT

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Abstract. *The increase of the cutting tool life in machining process has been challenging to process engineers. This article was developed with the main goal of compare the performance of the tools for tapping (taps) with and without tribological coating in the process of tapping the crankshaft. For this, it was evaluated the high speed steel HSS (substrate) produced by powder metallurgy and coated of titanium nitride – TiN coatings, titanium carbonitride - TiCN. It has been tested WC-Co tool. Preliminary tests were realized to prove the efficiency of WC-Co, that showed a productivity slightly higher than 5 times the productivity HSS tappings. It has also been proven that the greatest wear has been concentrated on the third taper of the tool, and also that the parallel threads have as function the calibration of the internal thread. The wear of the conical fillets was evaluated by the relation between the worn area and the total area of the fillet, which allowed to follow the process of wear of the tapping and to prevent the fracture of the taps. It was observed that wear mechanism of taps was abrasive and coating thickness decreased after pieces manufacturing to coated taps TiN /TiC.*

Keywords: machining, tapping, tribological coating, wear

Nomenclature

TiN	Titanium Nitride
TiCN	Titanium Carbon Nitride
EDS	Energy Dispersion Spectroscopy
HSS	High Speed Steel
WC	Tungsten Carbide

1. INTRODUCTION

1.1 General

In automotive industry, the increasing demand for lighter components has been enhancing the development of new materials. The austempered ductile cast iron has a mechanical resistance comparable to treated low alloy steel with low weight and cost(Da Silva , D. ; Hupaló, M.F.; Ferrer, M.H.; De Lima, N.B. 2007; França , A.B.C; Da Silva, E.R.; Carneiro, J.R.G. 2015; Hupaló, M. F., Ramos , D. S., Rabelo , A., De Lima, N.B. 2012). . Xavier, R. A. V. 2010 studied the roughing of turning of nodular cast iron engine crankshaft by comparative analysis of pieces obtained by sand or shell casting, using multi-layer coated tools. This machining goal is continuously challenged by the necessity of new machines, most of the times harder to cut, piece materials, restricted necessity of environmental conditions and by competitive pression to find the costs by manufactured pieces (Inspektor, A. ; Salvador , P.A. 2014). Surface coating is a effective method to improve the durability of machining tool utilized in agressives ambient. Coatings as TiN, TiC, TiCN, diamond like carbon (DLC), MoS₂ and some combinations as multilayer coatings have been using successfully.

Tapping is a process that produces internal and external threads widely used in industries of various ways and with many applications, but ordinarily with the objective of coupling parts. It is used because threading is a transient operation, which normally the duration of the complete cycle is a few seconds, so it is very fast, besides ensure precision and safety.

Threading is divided in two stages forward (subdivided into dipping and steady state of cut) and backward. The dipping state corresponds to the moment in which the cutting threads of the tap, i.e., the threads of the conical part and the first thread of the cylindrical part enter the part. In this state, shear forces vary over time. High performance tool can be utilized consistently and with previsible wear rate in higher cut speeds in tougher and longer period of time (tool life) cutting conditions. Machining process produces threads by removal of material (chips) and plastic deformation of material's part. The threads manufactured by rolling are preferable than the machined ones due to lower unit cost, superior mechanical properties and smaller material use. The rolling threading is a short term operation even in high cutting speed, this kind of operation is going to contribute to a global effort in industry in order to reduce production time, but it also should developed new materials to manufactured forming cores due to its longer lifes in service compared to cutting cores. In Brazil's industry, it is being used high speed steel (HSS) coated cores, this coatings are from TiN, TiCN, (TiAl)N and novel materials as WC/C e MoS₂ that is why their low friction coefficient and lubricant properties (Derflinger, V. ; Brandle, H. ; Zimmermann, H. 1999; Haigang, C., et al. 2001; Arndt, M. ; Kacsich, T. 2003; Reiter, A.E. ; Brunner, B. ; Ante, M. ; Rechberger, J. 2006). Failures can occur during threading operations as holes misalignment and breakage of cores fillets in entrance and ending of operation and also abrasive and adhesive wear of these fillets. Mezentsev, O.A. et al. 2002 developed a failure analysis system based upon mechanistic Threading model. Torque and force models were applied in laboratory tests measuring wear for small amount of thread produced using a scanning electron and a optical microscope (Reiter, A.E. ; Brunner, B. ; Ante, M. ; Rechberger, J. 2006; Gil-Del Val, A. et al. 2015 ; Wu, T.; Cheng, K. 2017). Studying performance of HSS coated with TiN, TiC and WC-Co in internal tapping by rolling of nodular iron crankshaft with a new technique of evaluation of wear of cores is the main goal of this work

However, this process comes with problems if not controlled can cause damages for machines and for the industries. The synchronism between the rotation and the feed movements is one of the most difficult parts of the process especially when using very high speeds. The wear is another problem that is very present in this type of process, and generate heat that led the chips adhere inside the part deteriorating the sharpness of the tap, and when the sharpness is damage, demand more energy from process and starts to increase the costs and the others problems as thread locking, clogging, or even breakage. Wear is an important parameter because it can helps or damage the process. A plethora of industrial processes aims to mitigate wear for need low energy to threading, besides increase the useful life time the tools and reduce costs.

1.2 Objectives

The main was to obtain the largest number of parts produced with a low amount of tools due to study was in a large-scale production process. For this, the effects and the change of tribological coatings on the productivity of threading tools in the machining process of the crankshaft were studied, analyzed and evaluated, which aimed to measure and compare the worn areas in the first three tool threads.

2. METHODOLOGY

The crankshaft showed in "Fig. 1" of nodular cast iron / GH-Type B, hardness of 240-290 HB, was manufactured by gravity foundry and it is necessary to undergo some procedures of machining to achieve final dimensions of assembly.



Figure 1. Crankshaft used in the study

The processes are divided in four phases in different machines objectifying the reduction of production time: facing end of crankshaft, drilling with center drill, drilling smaller thread diameter and thread bore and chamfer. If only one machine made all the processes, the time would be much bigger than divide in separate phases and machines. Other explanation to split the phases in different machines, is the possibility to choose and change the positions and parameters for each process and machine for after fix it and get the highest production possible. Besides that, if one process present some kind of problem, it would be easier to solve.

Currently, the holes tapping process are realized in an equipment called “Transfer Huller” as in “Fig. 2”. This machine allows the production of the thread in a sequential way, in which each cabin has a function, such as making the hole in the nodular cast iron of 11.04 x 31.5mm diameter before making the thread, widen the hole until it reaches the manufacturing cabin of the thread with the tool studied here. After that, they were liable to the fixation of crankshafts to engine gear. This process occurs in this way to increase productivity, so after 27 seconds one new threaded part was finalized.



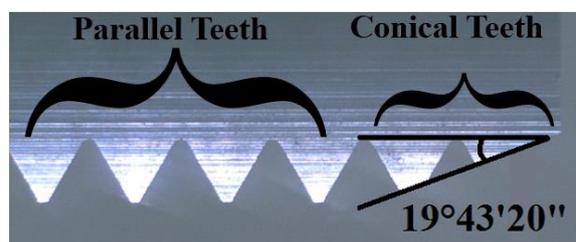
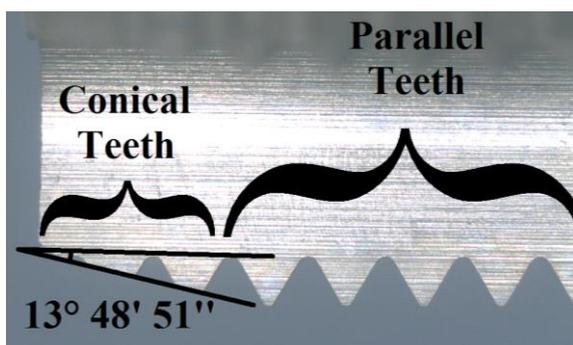
(a)



(b)

Figure 2. (a) Equipment used in thread production of crankshaft; (b) the same equipment, highlighting the cabin of making threads.

The tapping was made using two different types of geometry of threads with three and two conic taps and fifteen and fourteen parallels respectively as “Fig. 3”.



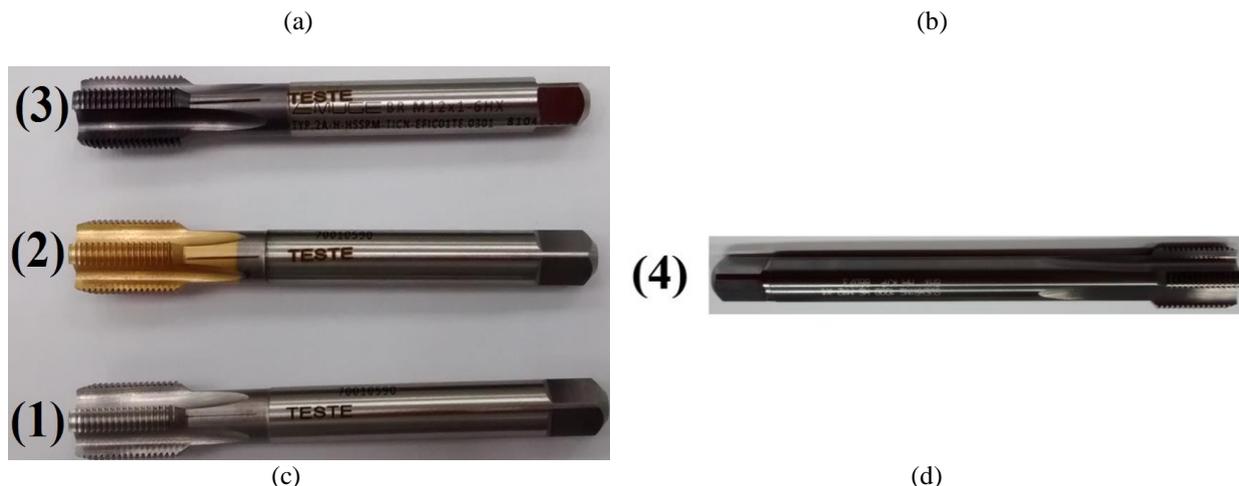


Figure 3. (a) HSS-PM tap geometry; (b) WC tap geometry; (c) Thread of (1) HSS-PM without coating, (2) HSS-PM TiN, (3) HSS-PM TiCN; (d) Thread of (4) WC-Co

This tests were made in Betim, Brazil with the parameters of “Tab. 1” for all tools.

Table 1. Parameters in which the tests were performed

Thread deep	27.8 mm
Cutting speed	11m/min
Feed speed	280mm/min
Rotation speed	280 rpm
Diameter	12 mm
Pitches	1mm
Depth of the thread	31,5mm
Temperature	± 25°C
Oil cooling	HOCUT 795, Houghton, with concentration of 6 to 8% in volume

The “Fig. 4(a)” shows the cores utilized in tests HSS-PM without coating, HSS-PM TiN, HSS-PM TiCN and WC-Co. They were fixed with a floating head because if there was some discordance of concentricity, the tool could finish the process without breaking.

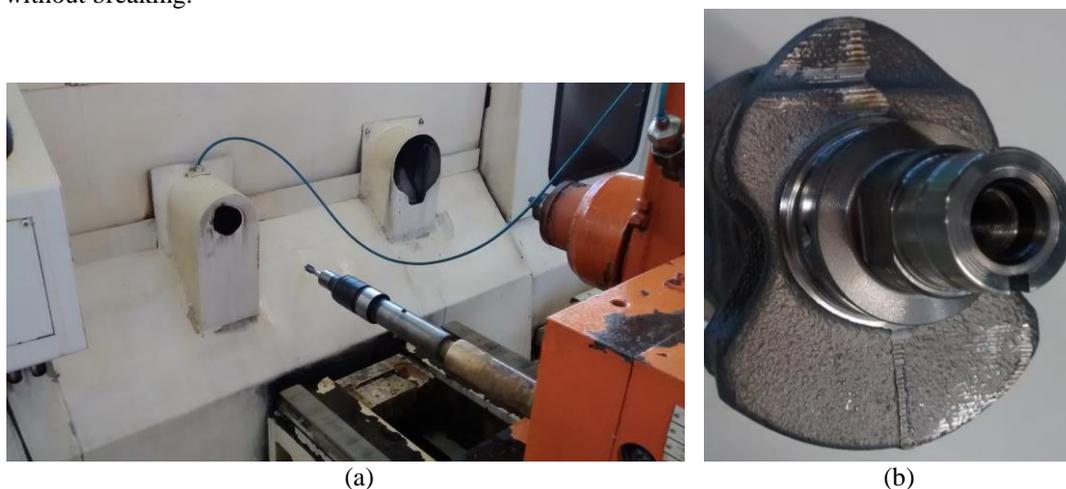


Figure 4. (a) Cores used to make the threads; (b) Crankshafts used in tests, highlighting the blind hole which the thread will be performed.

In order to ensure a good quality of the threads, quality tests were performed by sampling with a go/no go gage tool (Lumec) as shown in “Fig. 5”. On the left side, see the letter “P” and the threads that fit easily on this side, it means that they are within the tolerances pre-established, while the threads that fit on the right side referenced by the letters “NP”, mean that they do not fit as tolerances previously defined.



Figure 5. Instrument of calibration (plus-and-minus gage).

To follow the wear of each tool was used a machine with a high-resolution camera as “Fig. 6” that allowed to do an area analysis in the first three fillets, so that each period can be compared which fillet of which tool was most worn.



Figure 6. Machine that allowed measure the wear (Tecsart)

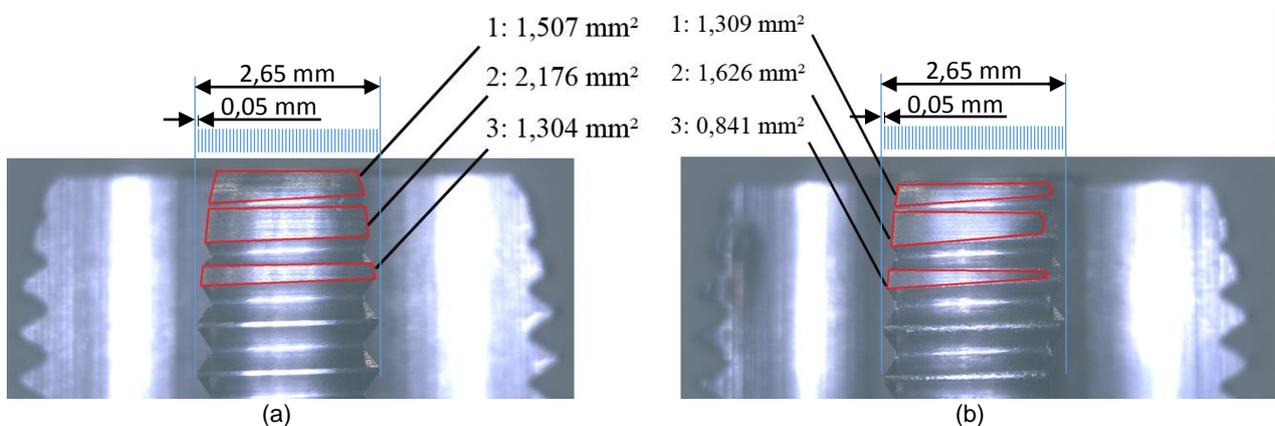


Figure 7. Examples of how the wear acts on the tool. (a) New HSS-PM without coating tap (b) HSS-PM without coating tap after 2100 parts.

3. RESULTS

3.1 Optical and SEM images and EDS (energy dispersive spectroscopy)

The “Fig. 8 (a-d)” shows the images of HSS steel tap. It was a high speed steel, tempering and quenched with some elements as W, V, Cr and Co shown in EDS analisys.

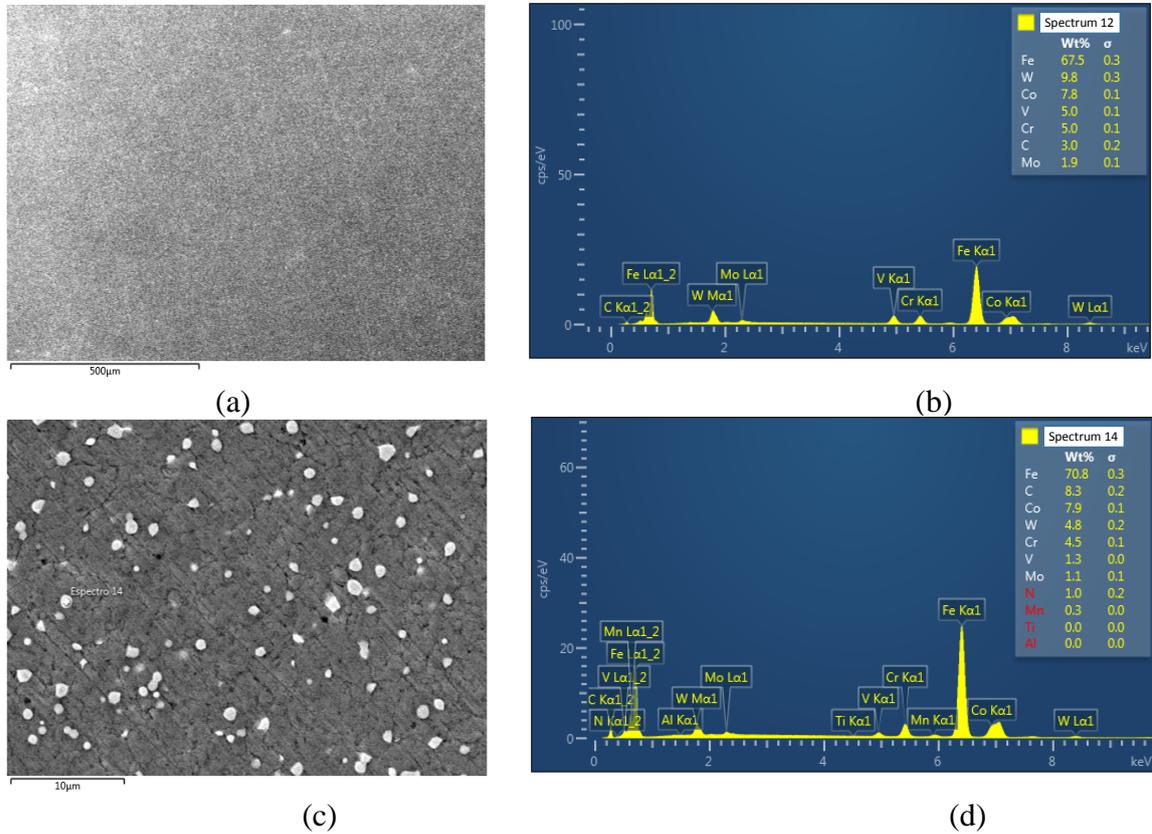
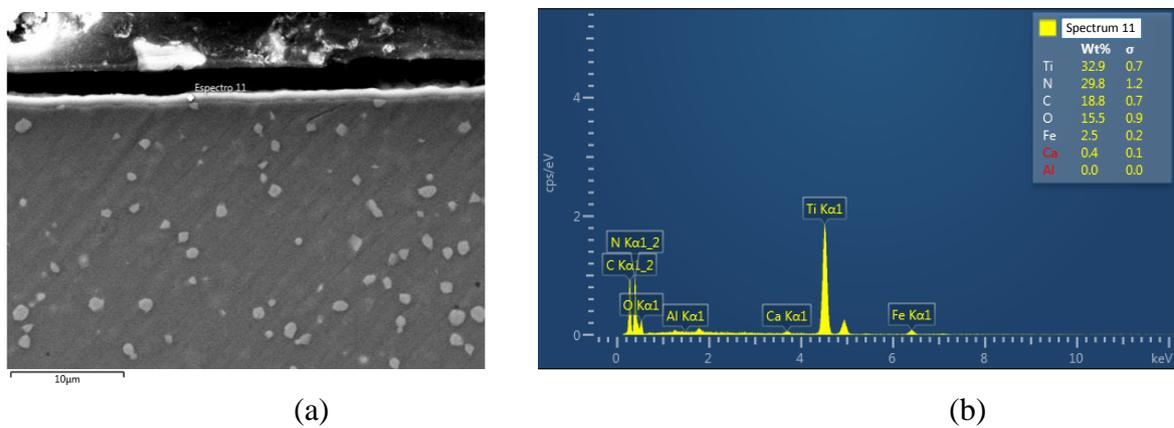


Figure 8. (a) View of HSS-PM; (b)EDS of HSS-PM; (c) View of HSS-PM particles; (d)EDS of HSS-PM particles

The “Fig. 9 (a-d)” shows the images of TiN and TiCN coatings with thickness close to 0,3 µm.



(a)

(b)

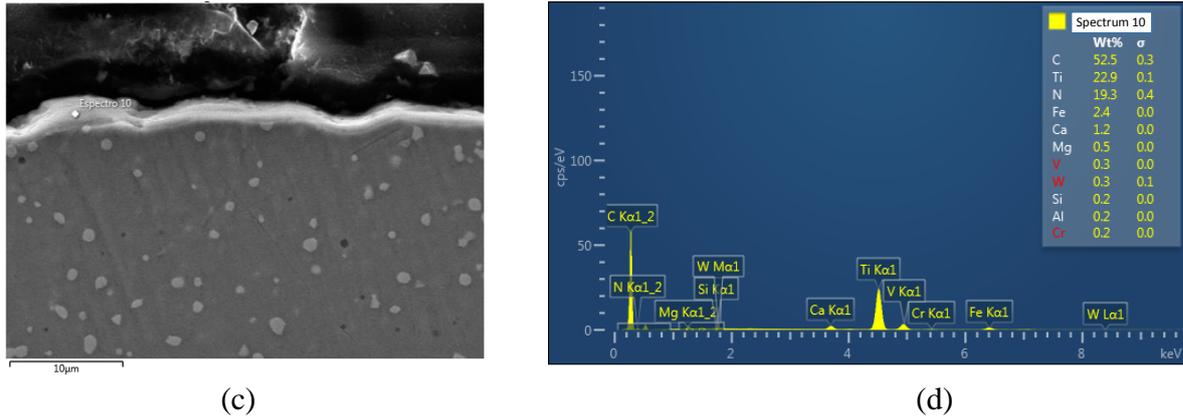


Figure 9. (a) View of HSS-PM TiN (b) EDS of HSS-PM TiN (c) View of HSS-PM TiCN (d) EDS of HSS-PM TiCN

It could be observed the chemistry composition of the substrate is the same in all taps with and without coating and coating has thickness approximately of 3µm showing PVD process. During the tapping process, this coating has been worn in the rake and flank surface with adhesion of nodular cast iron particles on the tools. This superficial layer aims to reduce the wear and improve the number of the crankshaft produced. It means that the useful tool lifetime increase, which leads to a reduction in production costs.

The “Fig. 10 (a-b)” shows the images of hard metal with WC and CrC particles in matrix Co.

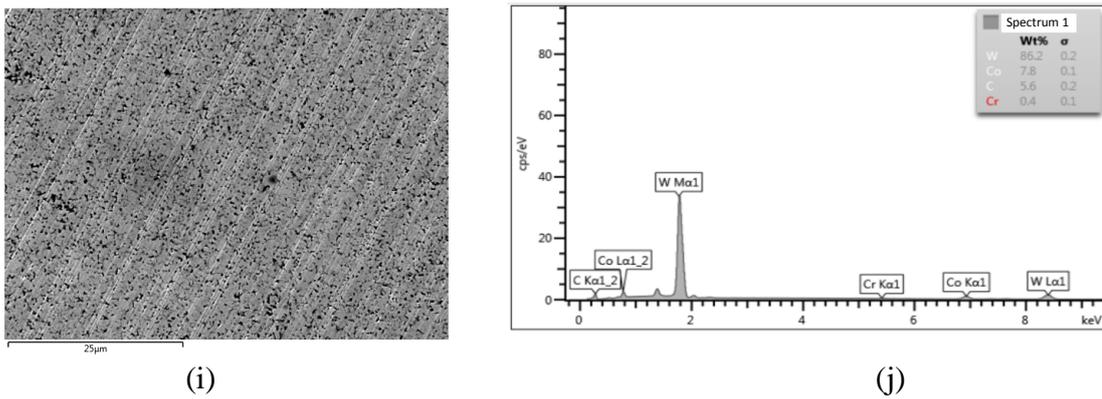


Figure 10. (a) View of WC-Co (b) EDS of WC-Co

Before the test, it was received taps with first and second tip of hard metal. It was produced another conical teeth in the production area (third tip).

3.2 Experimental procedure and results

After the tests, it was confirmed the number of crankshafts produced with their respective tap and it can be better visualized through “Tab. 2”.

Table 2. Experimental results for the maximum quantity of crankshafts were produced.

Type of Tap	Maximum Quantity of Crankshafts Produced
HSS-PM steel	2100
HSS-PM TiN	3300
HSS-PM TiCN	4000
WC-Co	11500

Despite the low cutting speed, the WC-Co presented the best result in relation to the productivity, as it was able to produce almost triple the tool's lifetime comparing to the TiCN coating, which is considered the second best tool when it comes to productivity.

3.3 Wear study in the taps and results

It was found that the malfunctions and wear of the cores that arose during the tapping operation occur in a greater degree on the edges of the conical region of the cores, i.e., the first three fillets, because this is the first portion of the core to perform the actions of cut, as verified by Dos Santos, Josué Olímpio et al. 2017. However, the analysis of the wear on the tools without and with coating happened gradually with the mechanism predominantly for "attrition". The wear was studied along the threading process considering the wear of the first, second and third conical threads. It was analyzed the worn out area for the three firsts taps because they are the firsts to contact to the nodular cast iron, suffering the greatest impacts of wear. It was analyzed with the number of crankshafts produced. This is an extremely decisive parameter, since it indicates where the tool is being more requested and therefore the useful life of the tool can be predictable. It can be better compared through graphs showing the wear area along with the quantity of crankshafts produced, such as "Fig. 11".

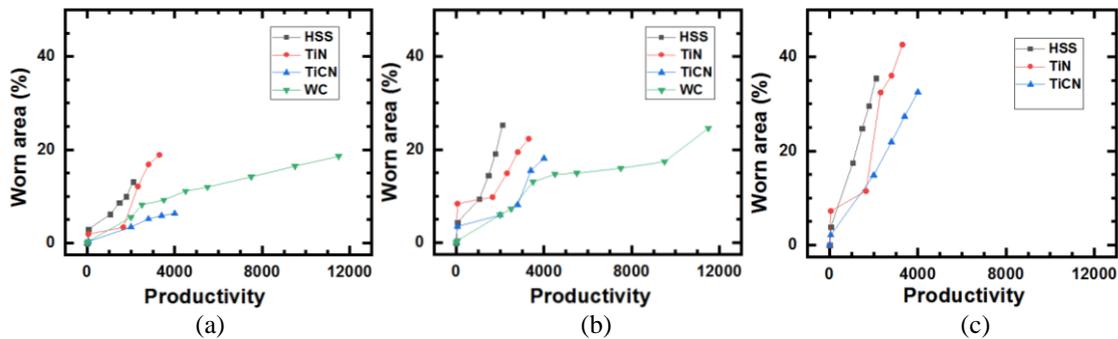


Figure 11. Evaluation of the (a) first; (b) second; (c) third fillet wear. Due to the WC not having the third conical fillet, the analysis of the third conical fillet was only made with the other three tools.

However, the best result is for WC tool, that exceeded the results of all other tools used in the study making more than double the considered second best tool and resisting much more time the were. WC tool with third tip produced in the area production has observed the best result with 18000 approved threads inspected by go/no go gages.

The WC tool has a peculiarity, while the other tools wear out during the process (abrasive wear "Fig. 12 (b)"), the WC splits at once such as "Fig. 12 (a)".

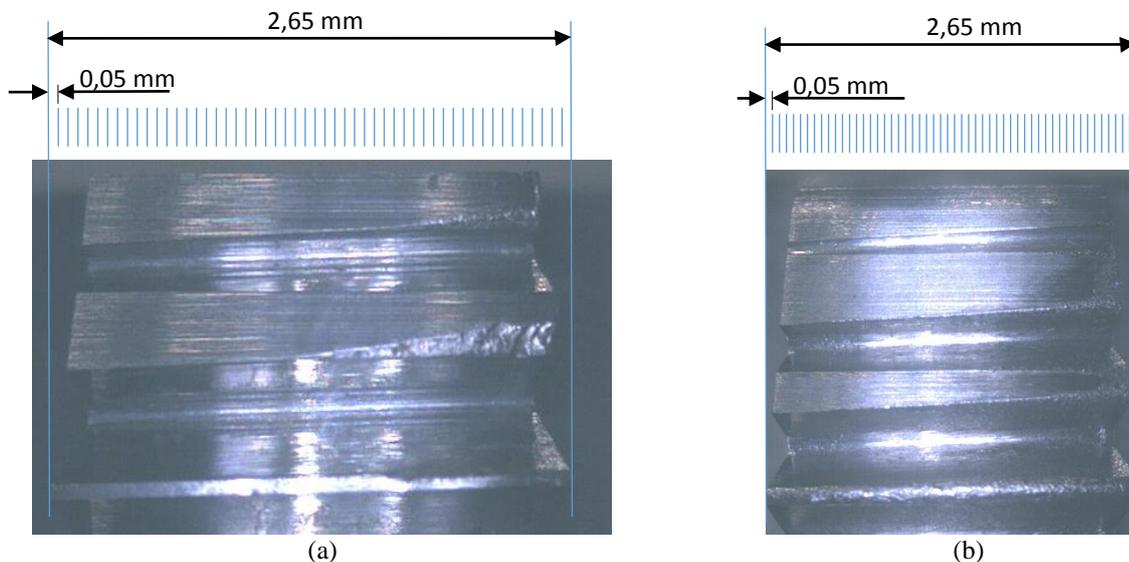


Figure 12. (a) WC-Co tap chipped; (b) HSS-PM without coating tap worn out

4. CONCLUSION

The first three taps wear more than the others taps on parallel region which define projected geometry. It happens because they are the first part of the tool to enter in contact with the material and real do the tapping.

It was noted that for the same number of threads produced, the wear of the first, second and third threads were consistently higher for the HSS core, in spite of the expectation for the greater wear would be in the WC, due the recommendation of manufacturer for not use WC tool with low cutting speeds.

The mechanism wear in WC tool was “chipping”, while PM steel with or without coating was abrasive wear.

5. ACKNOWLEDGEMENTS

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