EFFECTS OF THE TITANIUM CONTENT VARIATION IN THE LONGITUDINAL TURNING OF COMPACTED GRAPHITE IRON

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Abstract. *The mechanical properties of compacted graphite iron have brought many improvements for the use of diesel engine blocks, due to the fact that with this material high pressure can be obtained in combustion chambers, what decreases fuel consumption and pollutants' emission levels. Usually, alloy elements can be added, which improve its properties, but can decrease its machinability. This implies in an increase of cutting forces and a decrease of tool life. In this study it is analyzed the influence of titanium content in the tool life and the cutting power in longitudinal turning process, using carbide tools, cutting speed of 200 m/min, feed of 0.15 mm/rot, cutting depth of 1 mm, without cutting fluid. The machined alloys have content of 0.007% and 0.03% of titanium. Considering that the difference between the alloys is of 0.023% of titanium, the tool life for the alloy with 0.03% decreased an average of 2.6 times compared with tool lives obtained for the 0.007% Ti alloy. The main tool wear mechanism observed was attrition. Moreover, it could be verified a relationship between cutting power behavior and quantity of formed carbides in the material.*

Keywords*: longitudinal turning, carbide tool, tool wear, cutting power*

1. INTRODUCTION

Due to the desired mechanical and physical properties in compacted graphite iron (CGI), cylinder blocks, heads, brake drums and discs, manifolds, turbochargers and even piston rings, have been produced with that material (Ecob e Hartung, 2004). With the several technologies for the casting process, CGI started to compete with gray cast iron and aluminium alloys in the manufacturing of these components. One of these developed technologies is the addition of alloy elements, which improve the mechanical properties of the material, but on the other hand, harms its machinability.

According to Dawson and Schroeder (2004), when Ti content is increased in the alloy, tool life decreases drastically. However, Ti addition becomes interesting in the manufacturing of diesel engine blocks, improving its resistance and allowing higher pressure in combustion chambers. This produces a better fuel burning and less residual release, following the environmental law requirements. Moreover, there is a considerable fuel economy.

The Ti content found in CGI is either, derived of scrap (0.005-0.02%), or is intentionally added (0.04-0.25%) to improve wear resistance or to increase the stable production of CGI. Depending on its content in cast iron, it also promotes the formation of both, more compacted graphite and pearlite in matrix, increasing its resistance (Shy et al., 2000).

Most of works done aiming to evaluate CGI machinability considers the use of this material with low Ti content (from scrap), but this element is not taken into account in the analysis of tool life. Xavier (2003) turned CGI with carbide, ceramic and CBN cutting tools and obtained positive results with carbide tool. Doré (2007) used carbide and two kinds of ceramic cutting tools and had also better results with carbide tool.

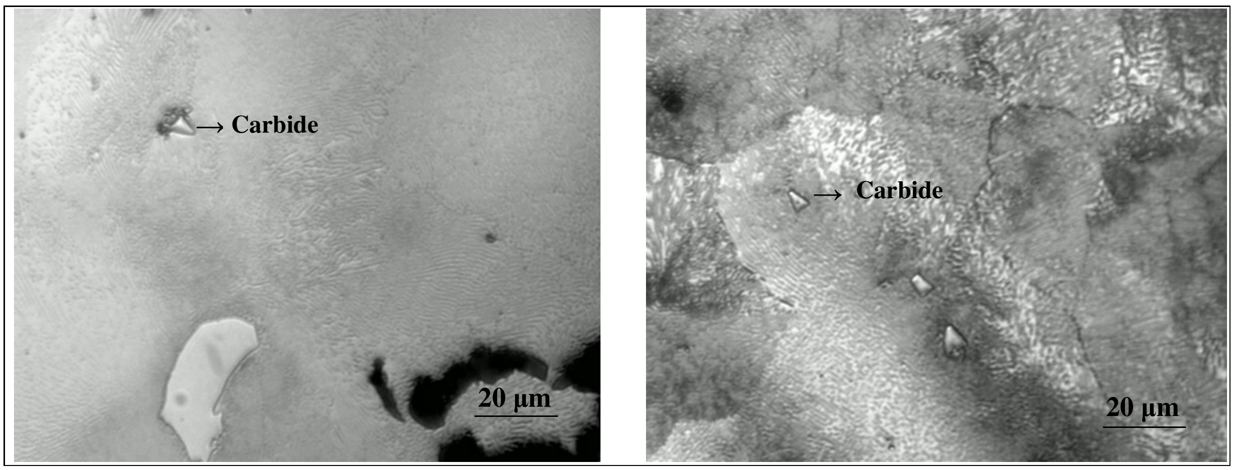
Considering these results, the tests in the present work were done with a carbide cutting tool. Moreover, it was evaluated the tool life for different Ti contents in the alloy, which due to carbide formation, harms the machinability, what is reflected in the high tool wear.

2. MATERIALS, METHODS AND EXPERIMENTAL PROCEDURES

Two compacted graphite iron alloys were studied: one with 0.007% Ti (alloy 1) and other with 0.03% Ti (alloy 2). Chemical composition, mechanical properties and some data of the alloy microstructures are shown in Tab. 1. It can be observed that the alloy 2 has higher Ti content and formed a higher quantity of complex titanium carbides (Fig. 1). Titanium carbides are angular inclusions, often cubic in appearance, are found throughout the matrix and are concentrated in intercellular regions (ASM Handbook, 1993). Alloy 1 is tougher, which can be verified by its percentual elongation. Another important difference between these alloys is the percentage of nodular graphites (graphite type IV). In alloy 1 is 7% and in alloy 2, 12%.

Table 1. Properties of CGI alloys

	Alloy 1	Alloy 2
C	3.41	3.35
Si	2.37	2.41
Mg	0.012	0.013
S	0.009	0.008
Ti	0.007	0.03
Hardness (HB)	231	245
UTS (10^6 MPa)	517	490
Pearlite (%)	98	99
Graphite	III 93% - IV 7%	III 88% - VI 12%



(a) (b)

Figure 1. Micrographies for analysis of the titanium carbides (a) alloy 1 e (b) alloy 2

The tests were conducted in a CNC lathe Romi Galaxy, with maximum power in the main motor of 15 kW and maximum spindle rotation of 4,500 rpm. In all experiments, the criterion to end one test was defined as the moment the maximum flank tool wear reached 0.3 mm. The cutting conditions were: depth of cut (a_p) of 1 mm, feed (f) of 0.15 mm/rot and cutting speed (v_c) of 200 m/min.

The machined workpiece has length of 200 mm, outside diameter of 142 mm and inside diameter of 92 mm and was fixed between lathe chuck and dead center. The used carbide tool was ISO K10 with three coating layers of TiN, Al_2O_3 and TiCN. Each experiment was carried out twice without cutting fluid.

In each cutting pass, flank wear was measured with an optical microscope Kontrol KET300. Cutting power signal was acquired with a sample rate of 100 Hz through the software LabView 8.0 connected to a computer and was processed with the software Scilab 4.1.2. After the end tool life, tool wear was analyzed in a scanning electron microscope JXA-840A.

3. RESULTS AND DISCUSSION

With the obtained results, it was possible to evaluate the difference between tool lives for the two studied alloys. Fig. 2 shows that the volume of chip removed per tool life to alloy 1 was approximately 2.5 higher than the obtained in alloy 2.

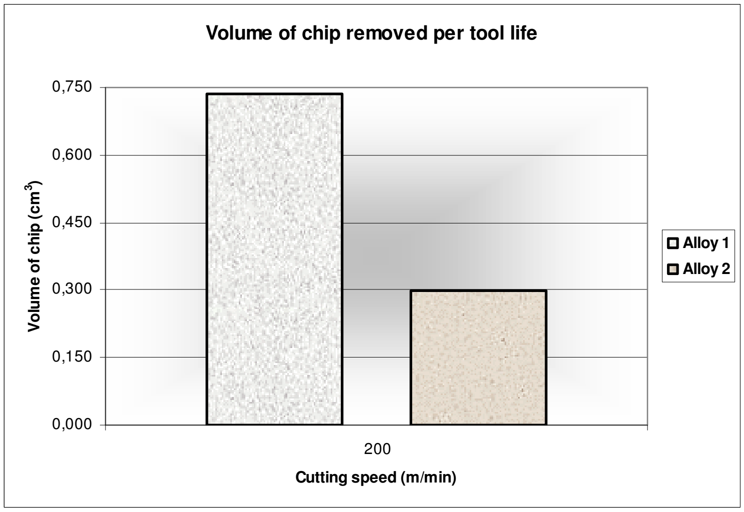


Figure 2. Chip volume removed per tool life for each tool material and alloys

Fig. 3 shows the flank wear land of the tool used to cut alloy 1 and fig. 4 shows EDS results for point 1, inside this region. Looking at the appearance of this flank wear land (Trent and Wright (2000), affirms that as attrition mechanism occurs in a grain level, worn areas have rough appearance) and the high content of Fe adhered, it can be said that the main wear mechanism verified in the machining of alloy 1, mainly at the end of tool life, was attrition. In order to this mechanism occurs, the tool coating must be removed through abrasion, probably caused by the titanium carbides. It was also noted the tool tip micro chipping (Fig. 3) caused by the weakening of the edge due to the wear and also by removal of large particles due to the stick-slip process typical of attrition mechanism. Other possibility to cause edge micro chipping is mechanical fatigue. This possibility will be discussed later.

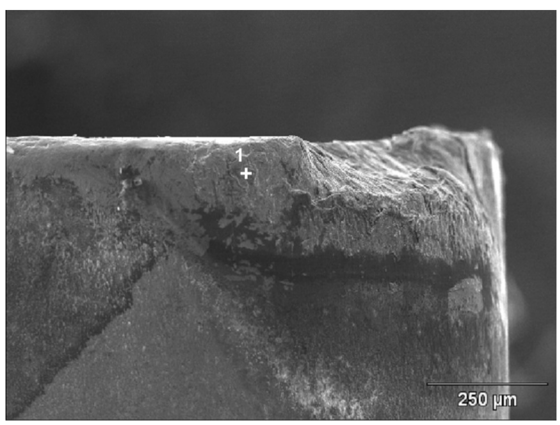


Figure 3. Cutting edge of the carbide tool used to cut alloy 1, at the end of its life

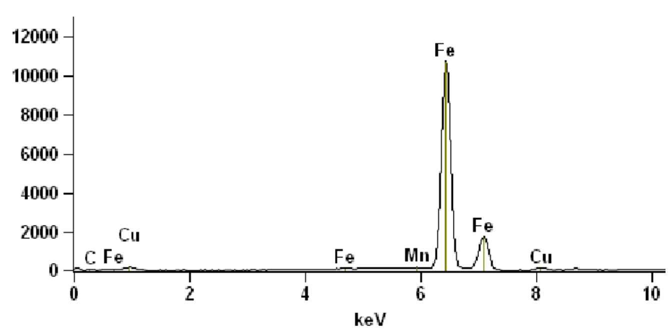


Figure 4. EDS analysis of point 1 of Figure 3

During machining of alloy 2, there was also adhesion of the workpiece material, as shown in Fig. 5. In the same way, point 1 shows where it was done the EDS analysis (Fig. 6), which also presents a strong concentration of iron in the flank wear land. In order to explain why this tool presented the shortest tool life, it must be remembered that seizure between tool and workpiece/chip material has to occur prior of the attrition wear and, according to Trent and Wright (2000), seizure just occur on the flank if the wear, caused by other phenomenon, is already present. Therefore, very likely, the high amount of carbides in alloy 2, caused wear by abrasion on the flank face very quickly, what allowed seizure and, consequently, attrition to occur.

It is interesting to note that this tool, which presented the shortest tool life, did not chip, as the tool that cut alloy 1. Therefore, it can be concluded that the longer life of the tool used for alloy 1, caused mechanical fatigue due to vibration. In order words, the inherent vibration of the process caused tool chipping due to the fact the wear last to reach the point of the end of tool life and, consequently, the number of tool-workpiece shocks caused by vibration made the edge chipping possible.

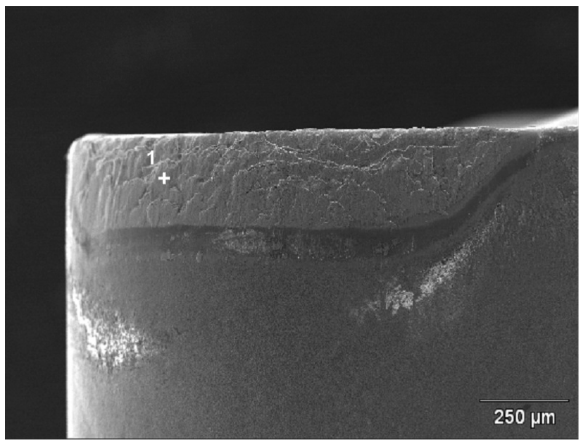


Figure 5. Cutting edge carbide tool used to cut alloy 2, at the end of its life

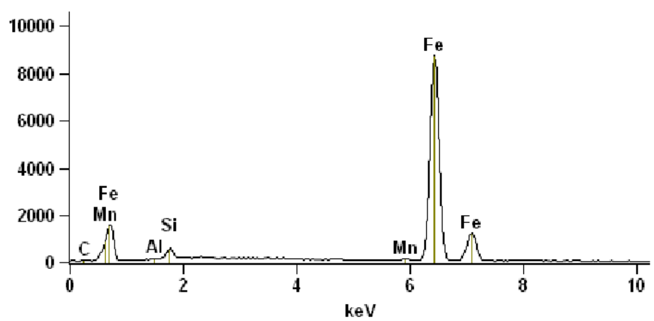


Figure 6. EDS analysis of point 1 of Figure 5

Fig. 7 and Fig. 8 show the evolution of wear and RMS cutting power values as a function of time to alloys 1 and 2, respectively. Considering the fact that the behavior of cutting power is similar to the observed in cutting force, both variables can be approximated to better interpretation.

Analyzing Fig. 7 (alloy 1) and Fig. 8 (alloy 2), it can be noted that both curves (cutting power and flank wear) increased over time, but the curves had different behaviors. It is shown in Fig. 7 that the cutting power curve has two regions: 1 (approximately 4 to 18 minutes) – cutting forces practically stay constant, with a low growth rate; and 2 (approximately 18 to 25 minutes) – cutting forces increase strongly. In Fig. 8, it can be seen that the power curve presents two similar regions when compared with alloy 1, but with a stronger growth rate in a bigger part. Both figures, the curve of flank wear was always increasing.

Observing the number of cuts in these graphics (Fig. 7 and 8), it can be seen that the increase of Ti content from 0.007% to 0.02% causes a decrease in tool life of 2.5 times.

In function of the higher tool life when machining alloy 1, attrition occurred more times, weakening the tool tip, what might have caused micro chipping.

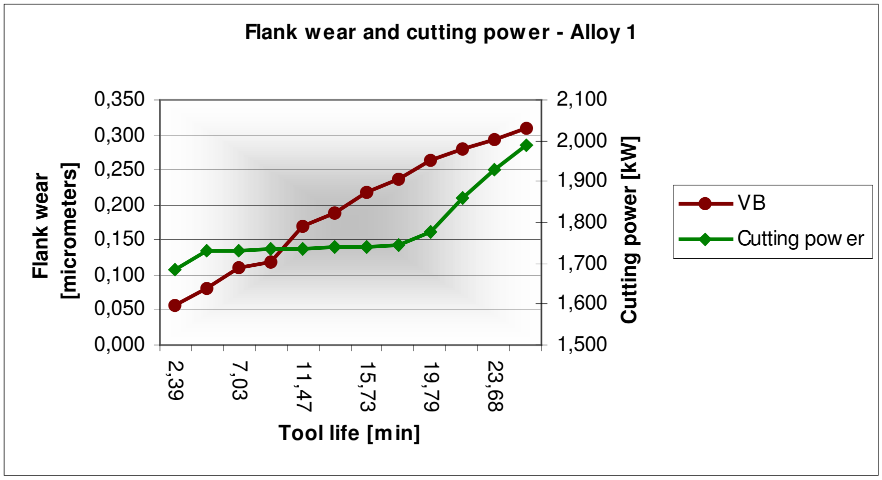


Figure 7. Flank wear and cutting power per tool life for alloy 1

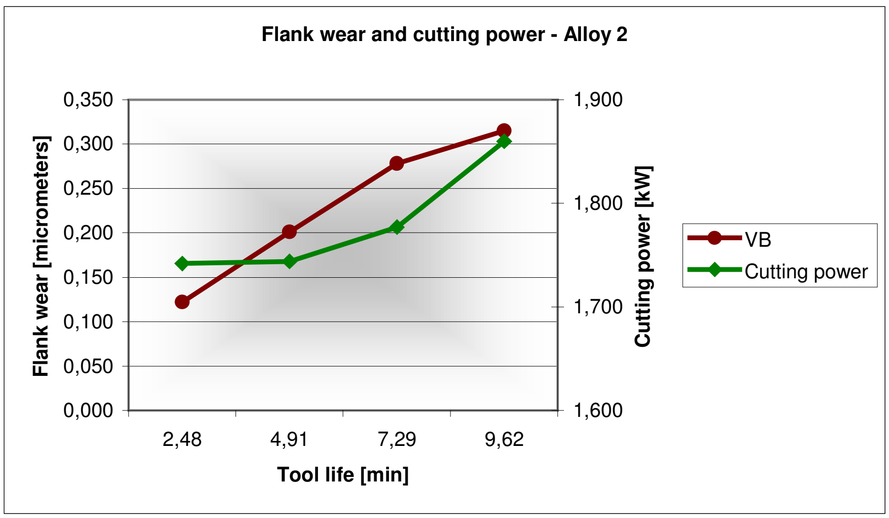
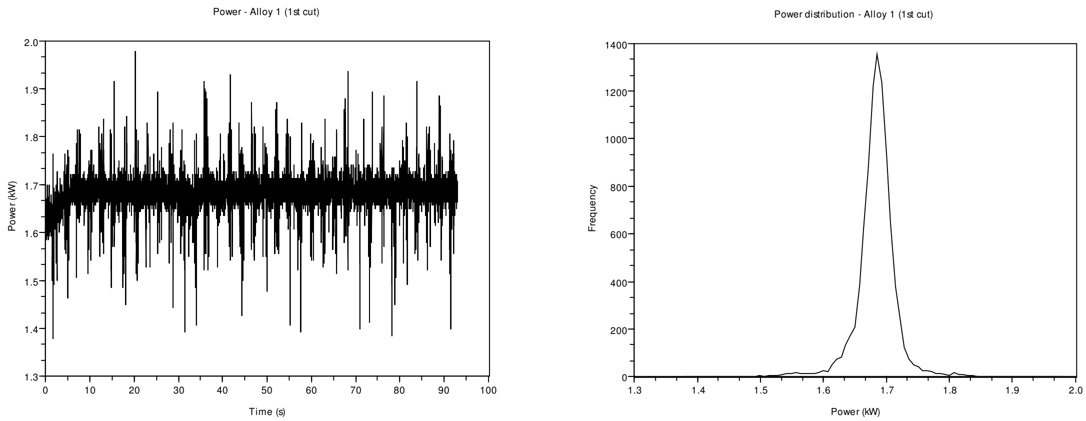


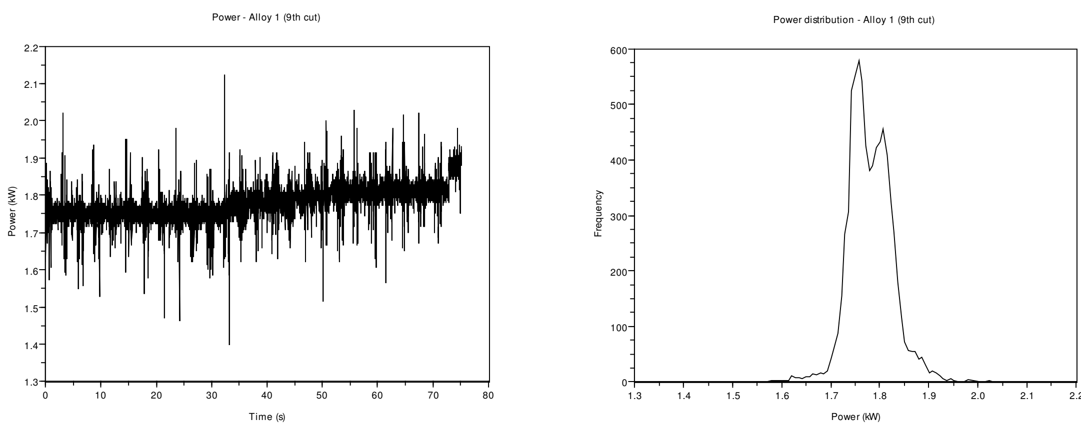
Figure 8. Flank wear and cutting power per tool life for alloy 2

The graphics of power signals and power distributions to each cut and alloy are presented in Fig. 9, 10, 11 and 12.



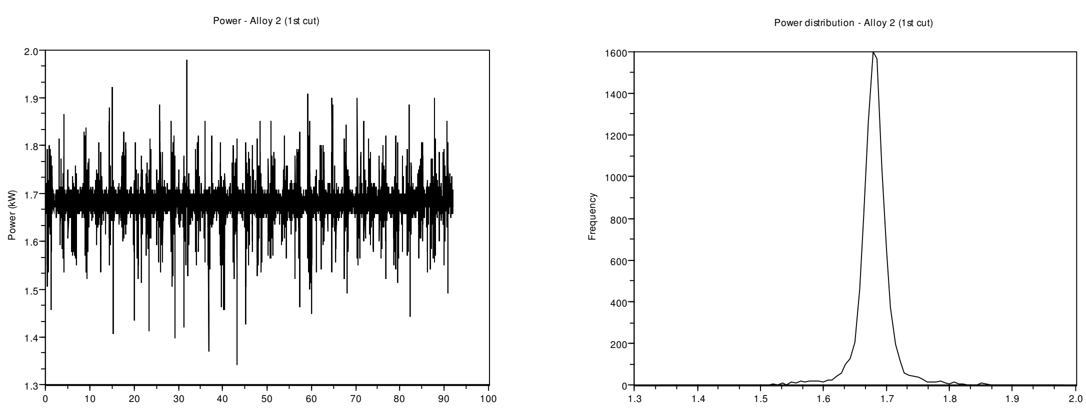
(a) (b)

Figure 9. Power signal – Alloy 1, 1st cut - from 0 to 93 s (a) evolution in time and (b) power distribution



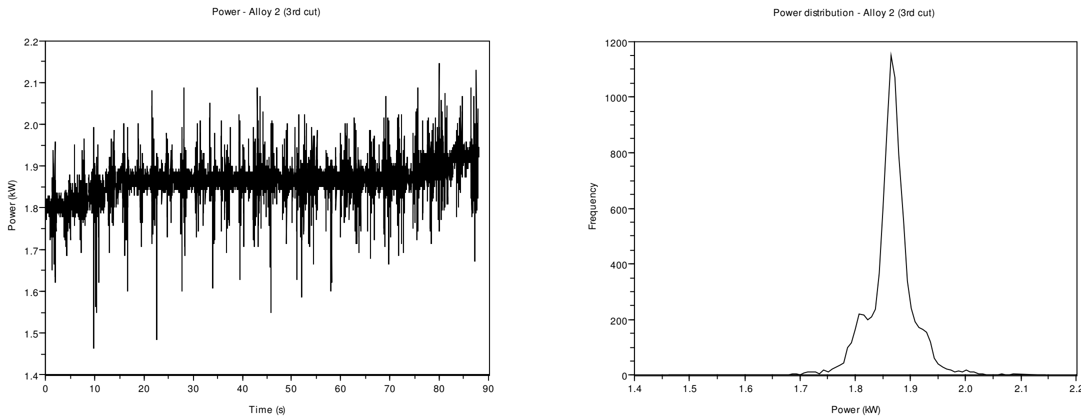
(a) (b)

Figure 10. Power signal – Alloy 1, 9th cut - from 1067 to 1154 s (a) evolution in time and (b) power distribution



(a) (b)

Figure 11. Power signal – Alloy 2, 1st cut - from 0 to 92 s (a) evolution in time and (b) power distribution



(a) (b)

Figure 12. Power signal – Alloy 2, 3rd cut - from 294 to 385 s (a) evolution in time and (b) power distribution

Initially it can be verified that the power values are allocated in an approximately normal distribution. In some cases, like in Fig. 10b and 12b, it is possible to observe the arising of two peaks, representing the simultaneous occurrence of two phenomena (Kume, 2003), what also can be evaluated in two levels which occur in the graphics of power in function of time. In this way, “double peaks” show the occurrence of a strong increase in tool wear during the cut, verified through the increase of forces. During the tests, it was seen that the appearance of “double peaks” was more often in alloy 2 and, generalizing, in Fig. 12b it was yet observed a tendency to the formation of a third peak of higher power before the end of cut, showing the higher wear rate in the machining of this alloy, what can be justified by the higher quantity of carbides founded.

4. CONCLUSIONS

According to the analyzed results, it was observed that the main tool wear mechanism in the machining of CGI with Ti addition is the attrition, due to the strong adhesion of workpiece material in the flank face of the tool, besides the abrasion caused by the carbides found in the alloys. The alloy 2, with a higher Ti content, caused a shorter tool life.

With the analysis of the rms values, it was possible to verify the increase of the cutting forces in relationship with the growth of tool wear. In the power distribution graphics, it was noted power fluctuations during some cuts (“double peaks”), showing an accentuated increase of cutting forces and, in the case of alloy 2, the more often occurrence of a higher quantity of carbides.

5. ACKNOWLEDGEMENTS

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