INVESTGATION OF THE MACHINABILITY OF ALLOYED GRAY CAST IRON (CrCuSn and CrCuSnMo) AND COMPACTED GRAPHITE IRON ASTM 350

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Abstract. *Cast iron is used to manufacture engine blocks because its mechanical and physical properties. The thermal conductivity and dumpy capacity are some properties fundamental tio these applications. Compacted graphite iron (CGI) has higher mechanical strength than gray cast iron and can be a great advantage in these type of mechanical parts. Alloying elements are also used to increase mechanical resistence of gray cast iron, resulting in a material with similar properties to the CGI. Futhermore the compression rate of the engine can be increase resulting in a higer efficiency. Althought mechanical and physical properties are similar for the both material, CGI is considerate to have poor machinability compared to gray cast iron, even for alloyed material. These means it is important to investigate the behaviour of the CGI for the most important cutting process. The main objective of this work is the investigation of the machinability of two types of alloyed gray cast iron (CrCuSn and CrCuSnMo) and the compacted graphite iron class ASTM 350. Tool life test were carried out in a milling operation and the flank wear mechanisms. It was used cemented carbide tools coated with* Al_2O_3 *over a layer of TiCN. All the test were carried out under dry conditions. Feed rate per tooth and depth of cut were constant, 0,2 mm/rev and 1 mm respectively. It was used three values of cutting speed, 600, 800 and 1000 m/min. the results shown that the gray cast iron alloyed with CrCuSnMo is the most difficult to machine material at the higer cutting speeds. At the cutting speed of 600 m/min the CGI is the most difficult material.*

Keywords: *compacted graphite iron, gray cast iron, machinability.*

1. INTRODUCTION

The cast iron industry is making continually development in the manufacturing processes and also in the material itself. These developments as a result of demand from the applied areas or cost reduction mean the technological improvement in a material of long tradition in the automobile industry (Guesser, 1997). The main application of cast iron is in automobile parts which demands improvement in researches to best understand the behavior of these materials according to the manufacturing process. Investments in researches and development of new products in this field became a key factor in the market.

In some applications a new material is always a target for improvement in the performance of a product. New materials for engine and head blocks for diesel motors for example, have been developed to help a motor to increase the thermal efficiency with a minimal environmental impact. Actually the development of new material to decrease the environmental degradation has been a drive gear in new materials development.

Gray cast iron, the most traditional material applied in the manufacturing of engines blocks and parts, reached the limit of strength, and an increase in the pressure in the chamber is possible only with the increase in the thickness of the engine walls. This means an increase in the weight and a lack of specification (CIMM, 2002).

The compacted graphite iron (CGI) is a material that presents properties of thermal conductivity and dumpy close to the gray cast iron but has superior mechanical properties. The manufactured parts have therefore, lower weight, best performance which ends in low pollution gases and noises. This material allows a higher pressure in the chamber, and the fuel is best used (Hick and Langmayr, 2000). However the CGI has a poor machinability compared to the gray cast iron, resulting in higher cutting tool wear and lost in the productivity (Marquad et al, 1998). Intense research in the development of this material and the improvement in the manufacturing process are therefore necessary.

In the CGI the carbon atoms that are retained in the matrix of the material became graphite in a shape similar to vermin. The morphology of this graphite are interconnected with the ends curved and random oriented, which results in a higher mechanical resistance compared to gray cast iron because this morphology is a barrier to crack propagation (Diniz, 2006; Guesser, 2002).

The machinability of CGI decreases even more when high cutting speeds are used, increasing heat generation and decreasing tool life. One of the most critical cutting operations is the boring of the cylinders encouraging the manufacturers to invest in researches to enhance the cutting processes of CGI (Mocellin, 2007; Reuter, 1999). Three main areas of development can be highlighted: improvement in the machinability, enhanced the machining process and development of new tool materials (Dawson et al, 1999).

The main objective of this work is the investigation of the machinability of two alloyed gray cast iron (CrCuSn and CrCuSnMo) and the compacted graphite iron of class ASTM 350. The first two materials are current used in heads of diesel engine blocks. The cutting process used is face milling with no cutting fluid. It was used cemented carbide tools of class K coated with Al_2O_3 using the technique of chemical vapor deposition at medium temperature (MTCVD). The machinability of each material was evaluated by tool wear land.

2. METHODOLOGY

Machinability tests were carried out in face milling operation and the flank wear land was measured to monitor the tool life. It was used a milling machine tool model Interact IV manufactured by ROMI. It was used aggressive cutting conditions to decrease the duration of the tests. The cutting speed is well superior to the ones recommended for the tool maker. The tool insert used was a cemented carbide with specification 1505ZNE-KM K20D and alumina coated (Al_2O_3). This insert is used in the production line to machine the faces of the cylinder block and head that are bolted together forming a tight seal for the combustion chamber. This cemented carbide tool was developed specifically for vermicular cast iron cutting. The tool holder has a specification R365-125Q40-S15M, diameter 125mm and capacity for 8 inserts.

The cutting parameters were defined according to the production line and also based on preliminary tests carried out in the laboratory. For each cutting condition, the tests were repeated once. The final result of flank wear land is an average of the two tests. Table 1 shows the parameters.

Table 1 – Cutting parameters used in the machining tests

Test	1	2	3
v_c (m/min)	600	800	1000
v_f (mm/rev/tool)	2445	3259	4074
f_z (mm/rev/tool)	0,2	0,2	0,2
a_p (mm)	1	1	1
a_e (mm)	67	67	67
n (rpm)	1528	2037	2546

Because the irregular shape all the workpiece were machined to have two parallel surfaces before the machinability tests. This was also necessary to remove the surface after the cast process. It was removed a layer of approximately 3mm. Figure 1a shows the workpiece as received and after the preparation for the machining tests. Figure 1b shows the workpiece fixed in the machine tool using an appropriated vice.

(a) **(b)**

Figure – 1 (a) workpiece as received and after machined for the tests; (b) workpiece in the milling machine tool.

For each tool life test it was used all the eight inserts in the tool holder. Richetti el al (2004) has investigated the effect of the number of inserts in the tool life and concluded that it is inversely proportional to the number of tools used. Therefore it was decided to use all the inserts in the tool holder. This means that the cost related to the tool inserts was high, but the time and workpiece consuming was reduced.

The tool life tests were stopped after a defined volume of material removed, 4.921,2 cm^3, which correspond to the machining of five workpieces. Cutting power was monitored during the operation using an appropriated sensor connected to the main electrical motor of the machine tool.

The tool wear was measured using a stereo microscope Olympus with magnification of 45 times and image analysis software. The wear was measure in all the eight inserts and the larger flank wear land was defined as the final wear of the tool after the end of the test. The system to measures tool wear is shown in figure 2a. Figure 2b shows an example of wear of a tool after machined five workpieces at a cutting speed of 1000 m/min.

(a) **(b)**

Figure – 2 (a) equipment used to measure tool wear; (b) tool wear obtained at the end of a test for gray cast iron (CrCuSnMo), magnification of 45x

Table 2 presents some mechanical properties for the three materials used in the tests. Material A is the gray cast iron alloyed with CrCuSn and material B alloyed with CrCuSnMo. The third material, C, is the vermicular cast iron. These properties were measured by Naves (2009).

Table 2- Mechanical properties of the workpiece materials.

	Material A	*Material B*	*Material C*
Tensile strength (MPa)	226	250	372
Hardness (HB)	216.4	223.5	174.9
Microhardness (HV 01) on pearlitic	320.3	330.1	341.6
Thermal conductivity* (W/mK)	50	45.5	37

* These values are related to measurements at 100°C (Guesser, 2005)

The microestructure for these three materials are presented in figure 3. It is possible to observe that the lamellar graphite is random distributed in a pearlitic matrix. Table 3 presents some information of the microstructure according to the material producer.

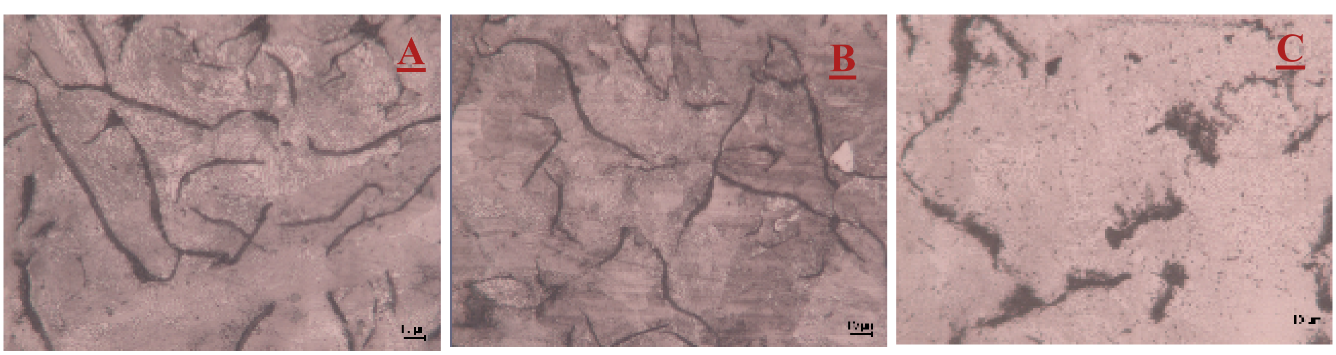


Figure – 3. Microestructure of workpiece materials, nital 3% and magnification 400X

Table 3 - Materials characteristics.

Material	*Matrix*	*Graphite*			
		Shape	Type	Size	Nodular
A	Pearlitic 100%	I	A	4 – 5	-
B	Pearlitic 100%	I	A	4 – 5	-
C	Pearlitic with 44% ferrite	III – VI	-	-	15%

3. RESULTS AND DISCUSSIONS

Figure 5 presents the results of tool wear for all materials and cutting speeds after machining 5 workpieces. These results represent the average of two tests.

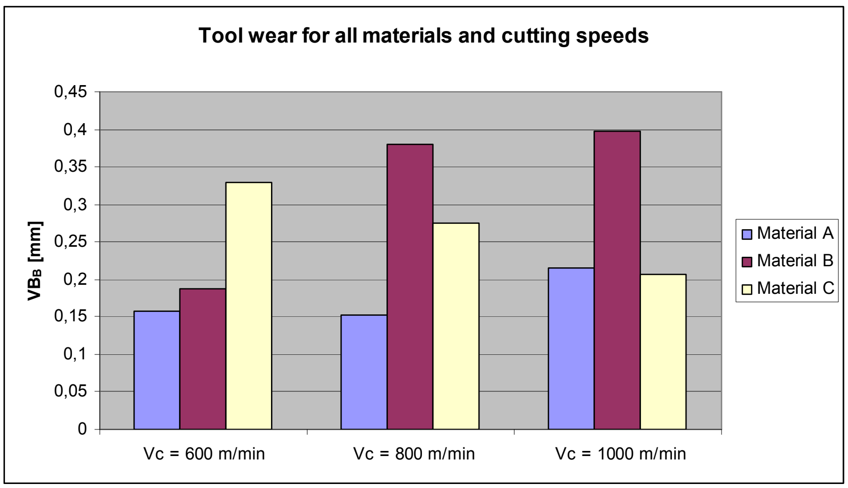


Figure – 5. Tool wear for all materials and cutting speeds

As was expected, material C, the CGI, is the most difficult to cut material while material A has the best machinability. This is because the morphology of the graphite. However this is true only for cutting speed of 600m/min, for the highest cutting speed both materials, A and C, have similar machinability. The average flank wear for these materials were about 200µm. It was expected a best behavior of the gray cast iron (material A) because of the morphology of the graphite. However this was not what happened at the cutting speed of 1000 m/min. According to tables 2 and 3 the mechanical resistance of material C is higher than A, however material A is harder than C. The microstructure of A is entire pearlite while C has 44% of ferrite. These properties are affected by temperature, which increase with cutting speed. The balance between these two mechanical properties is affecting the machinability. Figures 6 to 8 show the wear evolution during cutting time for all materials and cutting speeds. At the cutting speed of 1000m/min, flank wear for materials A and C are similar after 25 minutes. All curves have similar shape with exception for material B at cutting speeds of 800 and 1000 m/min.

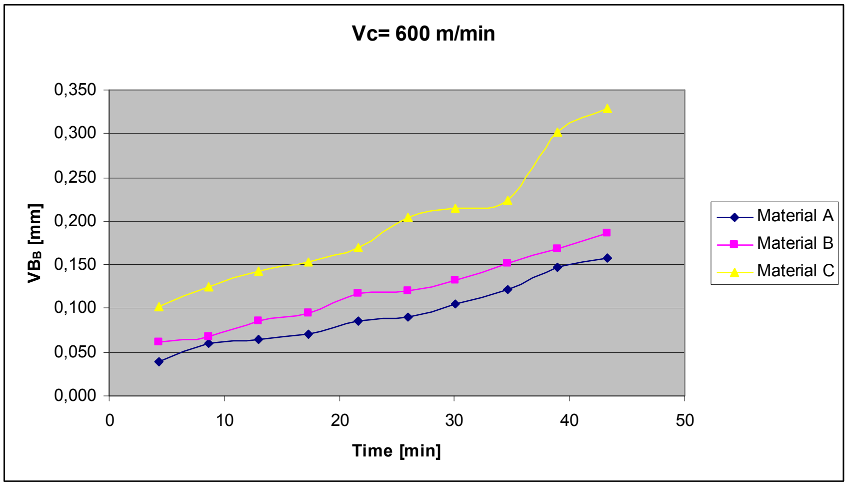


Figure 6 – Tool wear evolution for all materials and cutting speed of 600m/min.

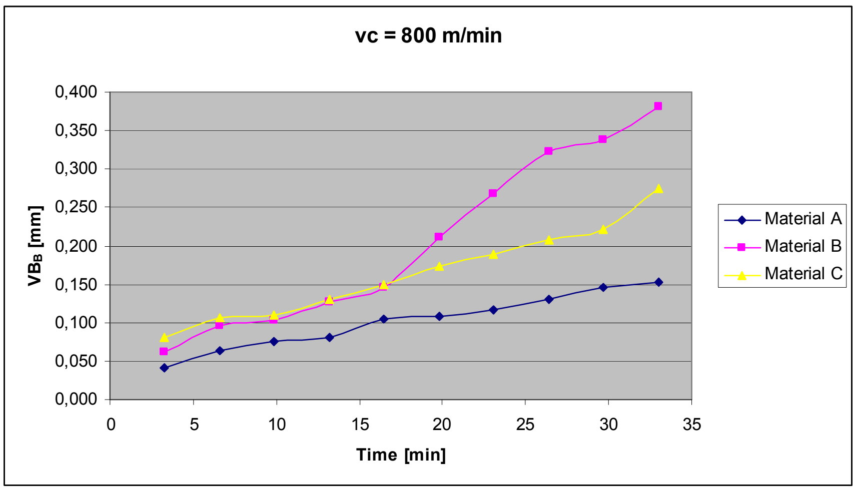


Figure 7 – Tool wear evolution for all materials and cutting speed of 800m/min.

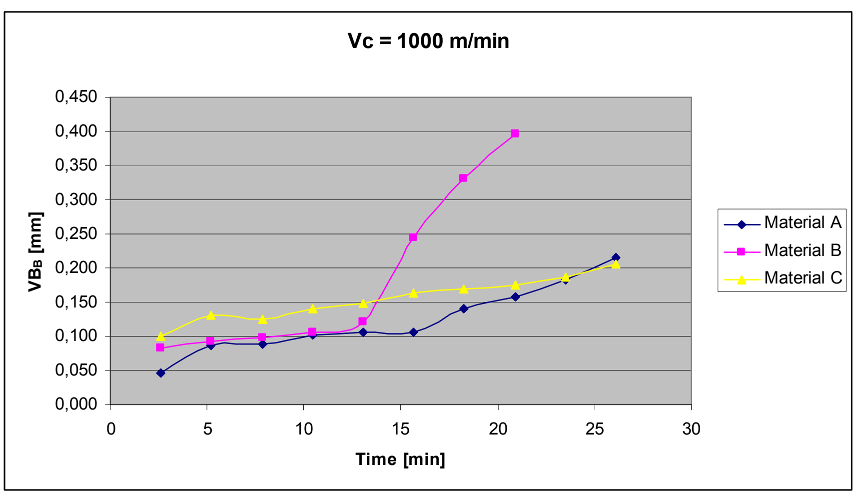


Figure 8 – Tool wear evolution for all materials and cutting speed of 1000m/min.

Figure 5 shows also that the alloyed gray cast iron CrCuSnMo (material B) is the most difficult material to machine at cutting speeds of 800 and 1000m/min. The alloying elements in the matrix of both gray cast iron affect the machinability. Chromium at quantities of 0,3% will precipitate and form complex carbides. These carbides will increase also resistance and hardness of the material. The copper will increase the machinability. The tin, at quantities between 0,1 and 0,15% is a pearlite stabilizer and does not form carbides. The effect of most alloying elements is based on the quantity of the pearlite and the decrease of the distance between the lamellas (resulting in a fine pearlite). The alloying elements can also increase the hardness of the ferrite (Santos, 1991). These effects suggest that a poor machinability can be obtained in a alloyed gray cast iron compared to the CGI. Molybdenum can form eutectic carbides which affect the strength and can be a key factor affecting the machinability. The presence and quantity of carbides were not evaluated in this work. This could be important information.

The cutting power necessary to machine these materials is shown in figure 9 for a tool at the end of life. The values are between 4 to 8kW. It is observed that the cutting power it well correlated to the wear evolution. The energy necessary to cut a material will increase with tool wear.

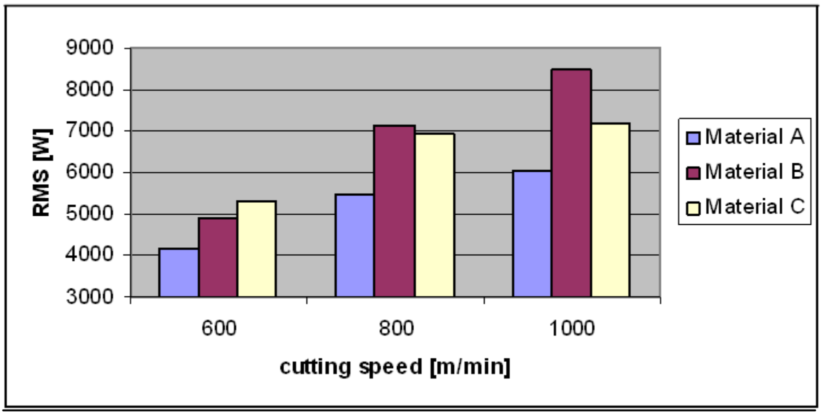
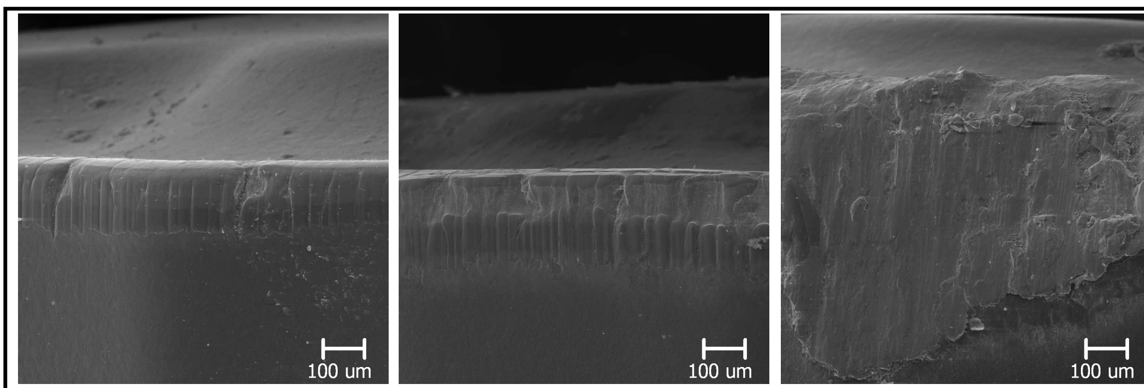


Figure 9 – Cutting power for all cutting speeds and materials at the end of tool life.

Figures 10 to 12 presents some scanning electron microscope photos of tool inserts used in the tests. It is possible to identify more than one wear mechanism. For the cutting speed of 600 m/min and materials A and B, the main wear mechanism is abrasion. For the other cutting conditions, adhesion was the main mechanism.



Material A Material B Material C

Figure – 10. Tool wear at cutting speed of 600 m/min

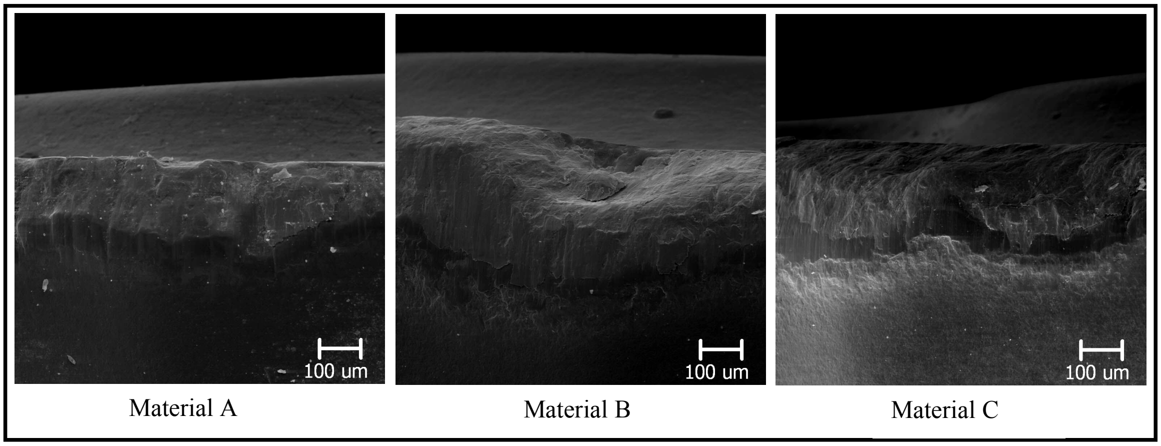


Figure – 11. Tool wear for cutting speed of 800 m/min

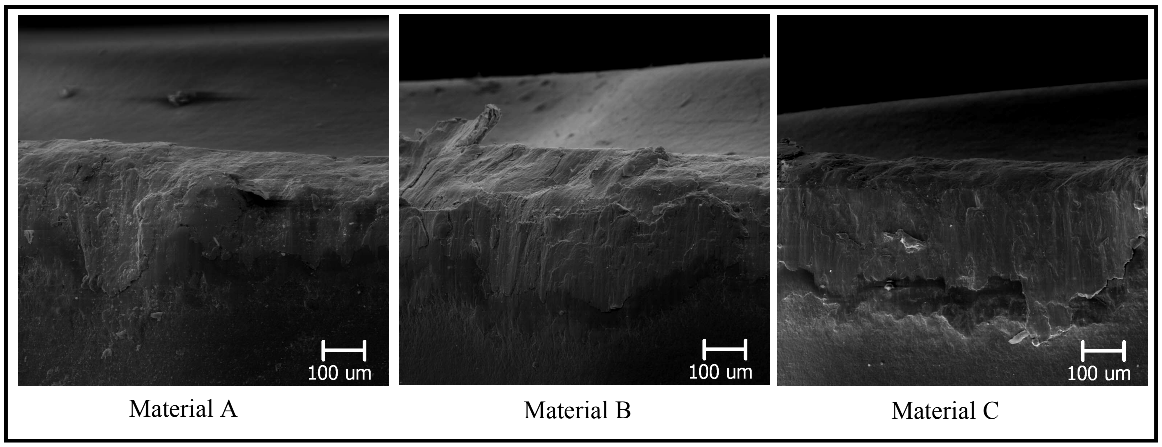
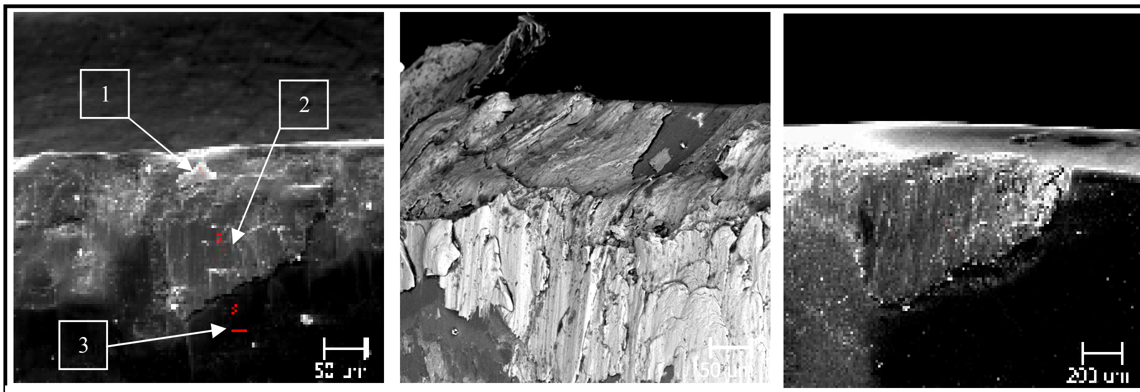


Figure – 12. Tool wear for cutting speed of 1000 m/min

Figure 13 presents more details of the tools to show workpiece material adhered to the tool material. In figure 13a the tool used to machine material A presents a strong adhesion of the workpiece material for the cutting speed of 800 m/min. Three regions in the tool was analysed using EDX. In region 1 it was observed a high concentration of iron and carbon, which can be from the workpiece material and the carbides of the tool material. Iron is also the material of the region 2 in the same figure. The material of the coating is present in region 3 because aluminum and oxygen were the elements detected.

Figure 13b shows the presence of iron on the cutting edge after machining material B at the cutting speed of 1000 m/min. Adhered material is also observed when machining material C (CGI) at cutting speed of 600 m/min, figure 13c.



[a] Material A, v_c = 800m/min [b] Material B, v_c = 1000 m/min [c] Material C, v_c = 600m/min

Figure – 13. Cutting edge after machining all materials at different cutting speeds

It is important to highlight that the cutting speed of 1000m/min can be considered high speed cutting (HSC) for these materials. The material behavior at such conditions of high temperature and strain rate is not known. It is important also to measure the thermal properties of the workpiece materials. The thermal conductivity for example, can be a very important propertie affecting tool wear. It is difficult to explain the unexpected behavior of materials B and C at 800 and 1000 m/min. Further machining tests will be carried out to get more information.

4. CONCLUSIONS

The main conclusions that can be obtained from the results of this work are:

• The CGI material presented poor machinability at cutting speed of 600 m/min. At the higher cutting speeds of 800 and 1000 m/min, the CrCuSnMo alloyed gray cast iron is the worst material to cut;

• The CGI and the CrCuSn alloyed gray cast iron have similar machinability at cutting speed of 1000 m/min;

• Flank wear was the main type of wear for all conditions and materials. The wear mechanisms observed at these conditions were abrasion and adhesion. Adhesion was the mains wear mechanisms at higher cutting speeds;

• The pearlitic matrix and, most important, the alloy element molybdenum, are the main factors affecting the machinability;

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