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EVALUATION OF TOOL WEAR WITH INTERNAL COOLING CHANNELS IN MACHINING GRAY CAST IRON
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Abstract. *Due to the competitive scenario experienced by industries, the search for better products ends up being the main focus of corporations. However, this technological dispute impacts the environment, which over time has been degrading more and more. Thus, the concept of triple bottom line (3BL) was developed, which comprises three pillars: environmental, with the objective of reducing impacts on the environment; social, which aims at the safety and well-being of the employee, in addition to the economic one, which aims at financial viability. Cutting fluids are of great importance in machining, such as cooling and lubrication, but they cause problems in the 3BL of the three aspects. For the most part, cutting fluids are toxic to both the environment and machine operators, in addition to having a significant cost in part value. This work aims to study the wear of tools in the machining of gray cast iron from an alternative technique of a cooling system, which aims to minimize or replace the use of cutting fluids, through modified tools with internal cooling channels (ICT) in the form of a closed system. Two variables were evaluated, cutting speed of 80 m/min and 125 m/min and the coolant medium, these being the ICT and the dry cut. A feed of 0.095 mm/rev and a depth of cut of 2.00 mm have been set. According to the results, the ICT tools had lower wear rates, however a small difference.*

Keywords: *cutting tools, tool wear, cast gray iron, sustainability, internal cooled tools.*

1. INTRODUCTION

Cast iron is an alloy composed of iron-silicon-carbon, which contains carbon contents above 2.0% in its composition (De Sousa *et al.*, 2018). According to the literature, cast iron is considered as a “ternary alloy Fe -C-Si" because the amount of silicon is greater than the amount of carbon, promoting a decomposition of Fe3C (Cementite) into iron, and carbon under lamellar graphite (Guesser, 2009).

Tool life can be defined by how long it can work efficiently, without losing its cutting capacity. Cutting speed is the parameter with the greatest influence on wear in a machining cutting tool. It is directly responsible for the temperature increase in the chip formation region, which is, by itself, what activates or accelerates the wear mechanisms presented so far (Machado *et al.*, 2015).

According to (Santos and Sales, 2007) the end of life of the cutting tool is determined according to its wear, which is dependent on several factors. Some of them are: fear of breaking the cutting wedge; temperature increase in the tool-part interface; rise in vibration level; increased machining force; surface finish and dimensional tolerance. To improve tool life, lubrication-cooling techniques are often used, such as the application of abundant cutting fluids, minimal amount of lubricant (MQL), cryogenic techniques, application of coatings or other alternative cooling techniques.

This work aims to analyze the wear of uncoated carbide tools in the turning of gray cast iron changing ambient conditions. As the main focus of the work, a new method based on the use of internally cooled cutting tools circulating water in a closed circuit with conventional dry machining tools was compared. This alternative method has already been studied in the works of (Bazon, 2020), (França, 2021) and (Barbosa, 2021).

2. INTERNAL COOLED SYSTEM

2.1 Cooling and Machining Subsystems

In comparison a conventional cooling system, this system is divided into 2 subsystems (Figure 1), the machining, on the left of the dashed line in green, and on the right, the cooling. In this cycle, what connects one subsystem to another are the hoses that circulate the fluid that cools the tool. The main purpose of the cooling subsystem is to cool a secondary fluid that will serve as a refrigerant for the machining subsystem.

The cooling subsystem used was a conventional cooling system, composed of the expansion device, condenser, compressor and evaporator. The evaporator is a reservoir that serves as a cooler for a secondary fluid, which in this case was mineral water. The water, when cooled in the reservoir, goes to the machining subsystem, to the left of the green line, circulating through the modified tool holder, clamp and tool, leaving the bottom of the tool holder and returning to the reservoir.

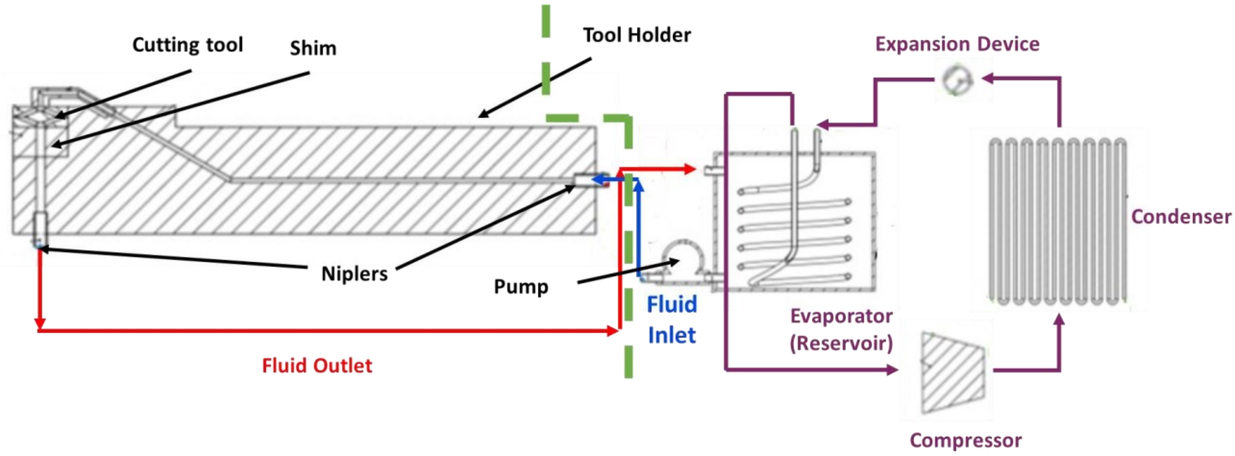

Figure 1. Machining and cooling subsystems.

2.2 Tool holder and modified tool

The Figure 2 shows a schematic drawing of the tool, where were produced by the company Mapal from Brazil, they are of K-10 grade carbide, with a 90º wedge angle, 1.00 mm nose radius and 0.06 mm chamfer in the horizontal direction and 0 .1 mm in the vertical direction, available in an angle of about 30.96º. The internal coolant channels of the tools were manufactured through the process of electro-erosion by a rotating electrode, and covered with silver solder. According the Figure 2, the arrows show the path of the secondary fluid inside the galleries, and the entry must take place on the upper face, through the contact with the clamp and the return through the lower face, through the shim and the shim index.

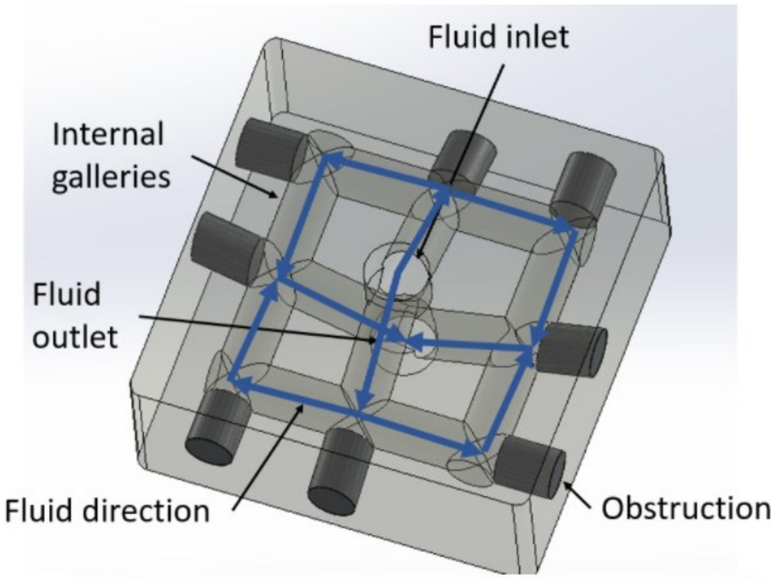

Figure 2. Schematic drawing of the tool galleries.

The internal channels of the tool holder of model DSSNL2525X12-P already had internal cooling channels (Figure 3). To carry out the project, the support underwent some changes in its structure, originally it had a fluid channel directed to the exit surface of the tool and another channel directed to the clearance surface, where the blue parts represent the internal channels in the port -tool. From the modifications made, the lower left channel was capped, and the clamp was altered so that the fluid could enter through the upper part of the tool.

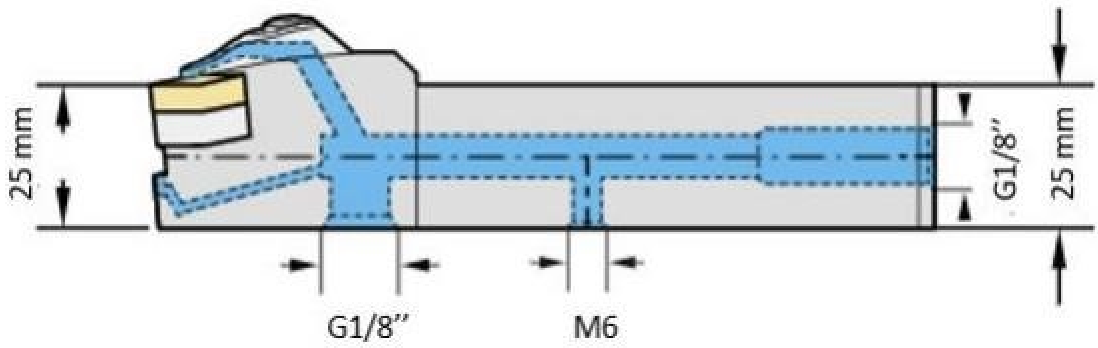

Figure 3. Original internal tool holder channels, (Walter Tools, 2021).

3. METHODOLOGY

The bars used were FUCO-300® gray cast iron in accordance with the ABNT NBR 6589 standard, with a diameter of 71 mm and a length of 305 mm. To study the influence of wear on the use of the cooling system in external cylindrical turning of gray cast iron, it was decided to use as cutting parameters two cutting speed levels, keeping the feed and depth constant at 0.095 mm/rev and 2 mm. It was decided to vary only the cutting speed levels due to its correlation with temperature which is related to wear. As ambient conditions, two levels were used, corresponding to the cooling process performed on the tool, being: dry (common insert) and water cooled to a temperature close to the solidification temperature (around 2 ºC). The water flow used in the tools was 500 ml/min. For each machining condition, a replica was made. Table 1 shows the cutting parameters used to carry out the tests.

Table 1. Cutting parameters utilized during for the tests.

Cutting Parameters	
Cutting Speed (m/min)	80 - 125
Feed (mm/rev)	0.095
Depth of cut (mm)	2.00
Enviroment (-)	Modified Tool - Dry

To measure the wear, the tooling microscope SZ6145TR from the manufacturer OLYMPUS was used with the ImagePro Express software, as a stopping criterion it was decided to use a machined length of 60 mm. To assess the wear mechanisms of all tools, a Hitachi Scanning Electron Microscope (SEM) model TM3000 was used.

4. RESULTS & DISCUSSION

Table 2 shows the measured wear for internally cooled tool (ICT) and common (dry) tools. It is observed that when comparing the conditions at the same cutting speed for dry and cooled tools, it is possible to observe that dry tools had slightly higher maximum flank wear compared to tools with internal coolant channels. This can be explained by the cooling that the internal coolant channels generate in these tools, causing a reduction in temperature throughout the tool region, reducing the wear rate. In the work of (França, 2021) temperature measurement studies were carried out using the tool-work thermocouple method and welded thermocouples along the system, where it was seen that this system was able to reduce the machining temperatures of gray cast iron in up to 21.52 %. In the machining of hardened steel AISI D6, (Barbosa, 2021) also observed temperature reductions using this system, in addition to lower wear rates, in which there was a 35 % extension in life. Through these works, it is clear that this system can collaborate in reducing temperatures and wear rates, however, reinforcing the statement already mentioned, in this study this difference was very small during the machining of this material, which could possibly have happened due to the lubricating action coming from the graphite present.

Table 2. Maximum wear length measured on principal flank surface of cutting tools.

Cutting Speed (m/min)	Environment	Test (mm)
80	Dry	0.995
80	Dry	0.888
80	ICT	0.629
80	ICT	0.603
125	Dry	1.402
125	Dry	1.393
125	ICT	1.311
125	ICT	1.371

In the analysis of tool wear, scanning electron microscopy (SEM) photos were taken for the principal flank surface (Figure 4) and rake face (Figure 5) of the tools. By comparing (a) and (b) which were as conditions of internally cooled tools and common inserts (dry) for a cutting speed of 80 m/min and a cutting speed of 125 m/min (c) and (d), it is clearly observed that the increase in cutting speed contributed to greater wear on the edges, a result already expected, since the increase in cutting speed leads to higher cutting temperatures, accelerating a wear rate (Trent and Wright, 2000).

Regarding the wear mechanisms, in general, the appearance of the worn regions, with a rough appearance, together with the amount of material adhered, clearly indicates that the predominant wear mechanism was atrittion (Figure 5d). Another wear mechanism that can be observed is abrasion, represented by the parallel arrows shown in Figure 5a. When particles of workpiece material adhered to the tool come loose, they flow through the tool surface, tearing off WC particles that are also stuck to the chip flow, they remove other parts of the material from the tool, causing an abrasive wear.

In general, most of the wear occurred on the flank surface of the inserts, with the predominant mechanisms being abrasion and adhesion, a result already expected in the machining of gray cast irons (Sousa *et. al*, 2018; Trent and Right, 2000).

When comparing the wear of the tools at the same cutting speed, it can be seen from Figures 4 and 5, a little difference in the wear of the edges machined at a cutting speed of 80 m/min. However, it is already possible to observe the beginning of a plastic deformation present in the tool chamfer. Apparently, the deformation in the flank of the dry-machined tool was a little higher, but there is no way to say this, due to the difficulty in viewing it due to the adhered material present on the edge of ICT condition (Figure 4a).

When comparing the conditions (c) and (d) of Figures 4 and 5, referring to a cutting speed of 125 m/min, it is already possible to observe a greater plastic deformation occurring in the tool chamfer, which is favored due to the increase in temperatures, causing a reduction in their thermomechanical resistances (Santos and Sales, 2007). In addition, it is also possible to see both in Figures 4 and 5 that the ICTs presented less plastic deformation in their chamfer and wear, which collaborates with the results obtained in the study by (França, 2021), indicating the probable reduction in temperatures on the edge during machining, thus generating lower deformation and wear rates.

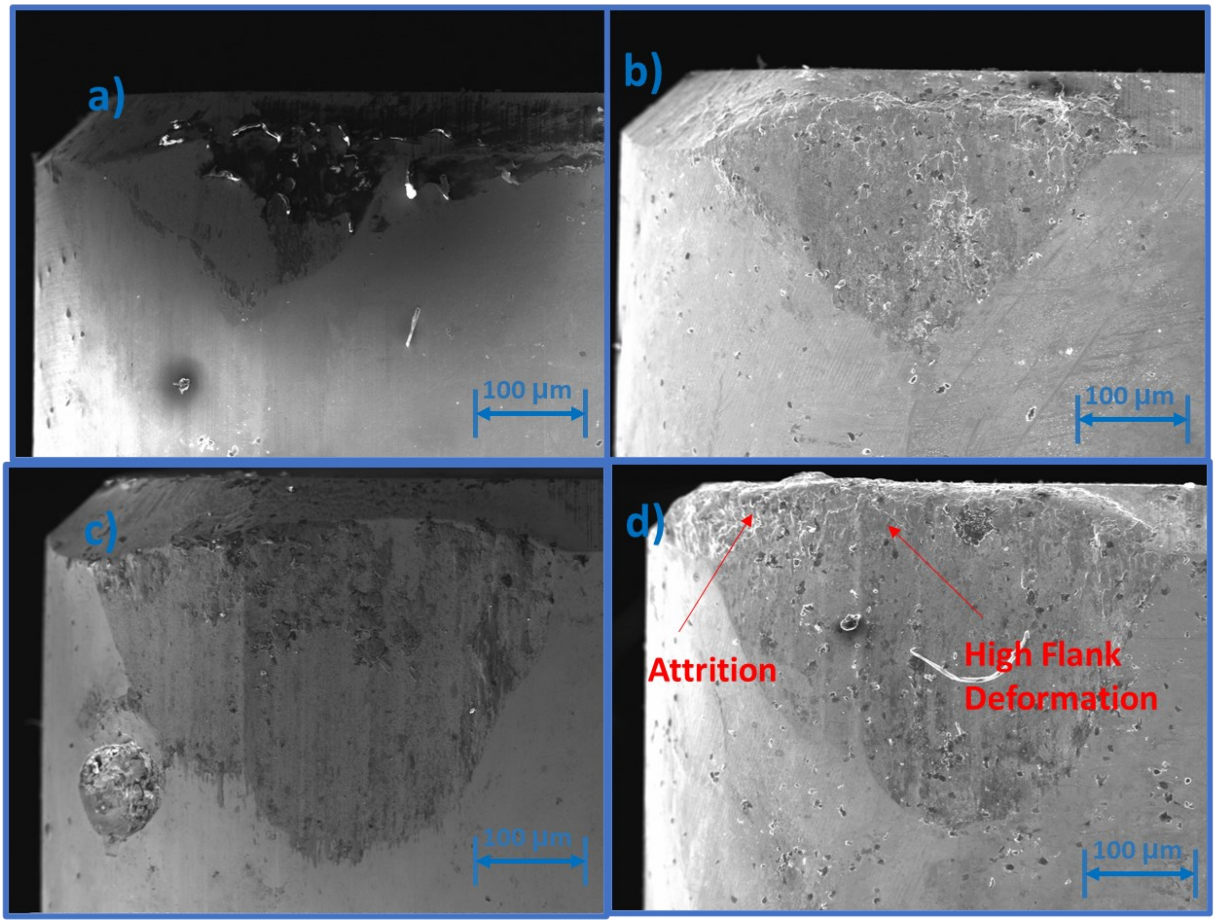

Figure 4 – Scanning electron microscopy of the primary clearance surfaces of the tools. a) internally cooled tool Vc = 80 m/min; b) Common insert (Dry) = 80 m/min; c) internally cooled tool Vc = 125 m/min; d) Common insert (Dry) = 125 m/min.

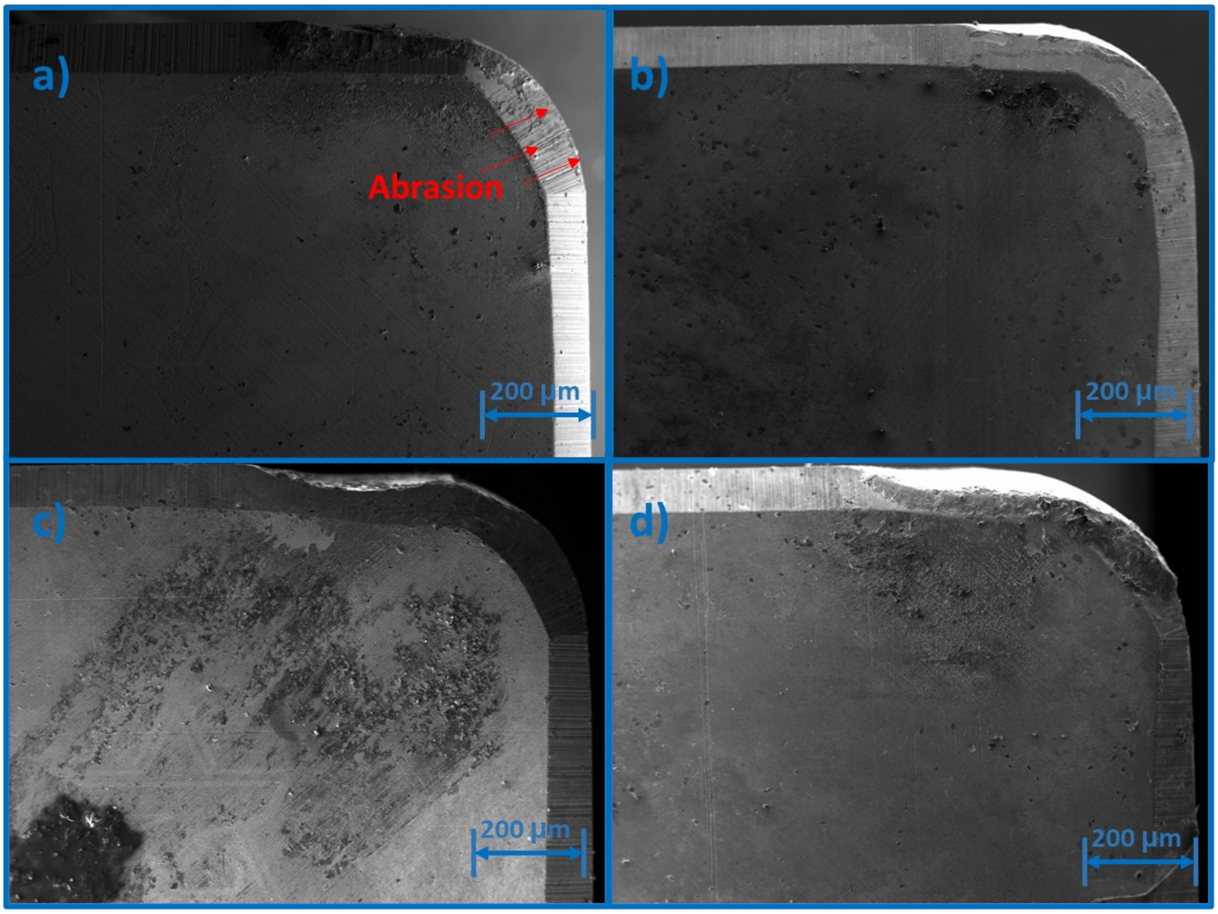

Figure 5. Scanning electron microscopy of the rake face of the tools. a) internally cooled tool Vc = 80 m/min; b) Common insert (Dry) = 80 m/min; c) internally cooled tool Vc = 125 m/min; d) Common insert (Dry) = 125 m/min;

5. CONCLUSIONS

After carrying out the tests, the following conclusions were obtained.

- The use of internally cooled tools could decrease the wear rate of the inserts. However, this wear rate was not significantly.
- Increased cutting speed resulted in higher wear rates.
- The predominant wear mechanism founded in cutting tools was adhesion, however the presence of abrasion marks on the tools was also observed, as the predominant type of wear in cutting tools was flank wear.
- The predominant type of wear on cutting tools was flank wear.
- At a cutting speed of 120 m/min a high plastic deformation was observed in the chamfer of the dry-machined tool compared to ICT.

6. ACKNOWLEDGEMENTS

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8. RESPONSIBILITY NOTICE

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