ANALYSIS OF THE INFLUENCE OF THE LUBRICATION AND COOLING CONDITIONS IN THE MACHINING OF STEEL SAE 1045

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Abstract. *Research in dry machining and minimum advantages and operators´ health, quantity of lubricant (MQL) has intensified in recent years. The operational, economic, legal and environmental provided by these machining techniques are encouraging factors for these matters to be searched. This project shows the influence of using three means of lubricating / cooling, dry machining, abundant gush of fluid and MQL. The machined material was steel SAE 1045. The manufacturing process used was the turning. During the turning process some cutting parameters, the cutting speed on three levels and the advance on two levels were varied. Through the output variables, the study verified surface roughness, geometric deviation, wear and damage of tools and chip formation which means of lubricating / cooling resulted in better machinability for the steel under study. The MQL showed the best results in general, the dry machining was good for the surface finish and the abundant gush of fluid brought favorable conditions for the formation of the chip.*

Keywords: *Means of lubricating/cooling, cutting speed, advance per revolution, machinability.*

1. INTRODUCTION

The machinability of metals has been a factor that brings great research in machining. According to Diniz et al. (2008) machinability is the "degree of difficulty of machining a given material." Among the factors that can influence the machinability of a material, we can mention the cutting parameters such as the cutting speed, the advance and means of lubrication / cooling (FERRARESI, 1970).

The cutting fluid is often used in factor of improvements achieved with its use, however, in recent years its use has become criticized because of the damage to operators´ health and to the environment when discarded incorrectly.

Before the drawbacks presented by the abundant use of fluid and expenditures provided for them, several cooling/lubrication methods emerged, which aim to minimize the consumption of cutting fluid or eliminate it completely, these machining systems are named machining with minimum quantity lubricant (MQL) and dry machining (PROJETO PROGRAMA PILOTO PARA A MINIMIZAÇÃO DOS IMPACTOS GERADOS POR RESÍDUOS PERIGOSOS, 2006).

2. THEORETICAL FOUNDATION

During the process of machining of metals, it is generated a large amount of heat, due to the effect produced by the cutting tool and the resistance of the material. Machining fluids are used in order to avoid the overheating of the tool and the workpiece, which fluids, due to their cooling and lubricant functions, avoid such a problem (PROJETO PROGRAMA PILOTO PARA A MINIMIZAÇÃO DOS IMPACTOS GERADOS POR RESÍDUOS PERIGOSOS, 2006).

According to Machado et al. (2011) the main functions of the cutting fluids are: lubrication at low cutting speeds; cooling the high cutting speeds; removal of the chips in the cutting zone and protection of the machine-tool and the workpiece against oxidation.

The application of the cutting fluid can occur in several ways. In the method of minimal quantity lubrication (MQL) oil droplets are released into the cutting area or directed by an air jet, that is, atomized, to the point where the machining is being performed to produce a protective lubricant film. The volume of fluid may vary depending on the volume of chips and the machining process. This minimal amount of fluid should be sufficient to reduce the friction of the tool and prevent adhesion of materials. (PROJETO PROGRAMA PILOTO PARA A MINIMIZAÇÃO DOS IMPACTOS GERADOS POR RESÍDUOS PERIGOSOS, 2006).

In this study it was used the method of application of external MQL by spray, in this system a device called a nebulizer aspire the fluid by an air flow created by Venturi effect and leads to the active surface as a mixture. This system needs to be adapted in the machine and yet requires a source of compressed air and a fluid reservoir, Fig.3 shows this adaptation in materials and methods.

In the minimum amount of lubricant it is used on average a flow of about 10-100 ml / h and pressure of 400-650 kilopascals (kPa) (ATTANASIO et al.2006 cited OLIVEIRA, 2011).

In the gush of fluid with low pressure, a high flow of fluid is used to operate in a small region with only refrigerating effect (Reis, 2000).

Souza (2014) conducted a search about the evaluation of technical / economic, environmental and social dimensions in the application of different techniques of lubrication and cooling. For this, she used the milling of Grey Cast Iron (CGI) using the dry Lubri-cooling techniques, MQL, and flood. The criteria used to measure the performance of each lubrication and cooling technique was the energy consumption of the machine, quantity of the volume of cutting fluid spent , air quality, residues generated and the operator´s health. For these criteria, she concludes that the dry lubrication and cooling technique is the most appropriate for CGI milling.

Islam et al.(2006) also conducted a search comparing the three lubrication and cooling techniques. They monitored the turning of Steel AISI-1040 investigating the cutting temperature, chip formation and dimensional deviation. They concluded that the MQL machining had a better result rather than the dry machining and the machining with flood, mainly because it contributes to the reduction of the machining temperature, decrease of the dimensional inaccuracy and benefit from the interaction between the tool and the chip.

The objective of this study is to compare the performance of different lubrication/refrigeration systems (abundant gush of fluid, MQL and dry machining) in machining SAE 1045 steel by performing turning tests at different cutting parameters. And with that, check in which means of lubricating /cooling the material showed better machinability. The criteria used were the chip formation, the wear of the cutting tool, the circularity deviation and the surface finish.

3. MATERIALS AND METHODS

The parameters of machining (Fig. 1) varied in the turning were: cutting speed of 125 meters per minute (m / min), 157 m / min and 196 m / min, advances 0.05 millimeters per revolution (mm / rev) and 0.1 mm / rev and means of lubrication/cooling gush of abundant fluid, MQL (minimum quantity lubrication) and dry machining (unused fluid).

Combination of machining parameters				
Advance	Cutting speed	Means of lubrication and cooling		
		Dry	Abundant fluid	MQL
0,05 mm/rev	125 m/min	1° assay	7° assay	13° assay
	157 m/min	2° assay	8° assay	14° assay
	196 m/min	3° assay	9° assay	15° assay
0,1 mm/rev	125 m/min	4° assay	10° assay	16° assay
	157 m/min	5° assay	11° assay	17° assay
	196 m/min	6° assay	12° assay	18° assay

Figure 1 - Combination of machining parameters

The machining depth is kept constant in the amount of 1 mm in all assays. The number of passes for each assay was 6.

The 2x3x3 factorial design was used to determine the assays. Thus the total number of trials was 18, to all conditions three replicates were performed. For each replica of the study five measures at different points of the specimen, were performed, chosen at random. The values shown in the results are averages of those 5 readings.

The experiments were performed on a conventional lathe which brand name was Romi, MS 205. This lathe has as main feature installed power of 7.1 KW, a minimum speed of 31.5 rpm and maximum 2500 rotation per minute (rpm) and maximum length 1000 mm between the tips.

The specimens for the experiments were made with steel SAE 1045. Composition and properties in Fig, 2. The dimensions of the specimens were 50 mm initial diameter and 100 mm in useful length for machining.

Mechanical Properties of the steel SAE 1045		Component Elements of the steel SAE 1045	
Hardness, Rockwell B	86	Carbon, C	0.42 – 0.50%
Tensile Strength, Ultimate	585 MPa	Iron, Fe	98.51 – 98.98%
Tensile Strength, Yield	505 MPa	Manganese, Mn	0.60 – 0.90%

Elongation at Break	12 %	Phosphorous, P	< = 0.040%
Reduction of Area	45 %	Sulfur, S	< = 0.050%
Modulus of Elasticity	206 GPa		
Bulk Modulus	163 GPa		
Poissons Ratio	0.29		
Machinability	65 %		
Shear Modulus	80.0 GPa		

Figure 2 - Mechanical Properties and Elements that make up the steel SAE 1045
Source: Matweb (2015).

It was used as a cutting tool a hard metal insert of Ceratizit brand identified as CNMG 120408EN-TM / CTC1125.

In machining with abundant fluid it was used the refrigeration system of the lathe, having a pump of 90 W, a reservoir, hose, and a nozzle adjuster. The flow rate used in this cooling/ lubrication system was 54.5 liters / hour and the fluid used was an emulsion of 1/20 (1 part oil and 20 water) of the UNIX brand.

The spraying of the fluid in the machining MQL was made with the use of the nebuliser TAPMATIC V (Fig. 3). This device sprays oil by spray method. During the assays the flow of fluid was set at 90 ml / h.

The air pressure used in the input of the device was regulated with a conditioning unit (Fig. 3) fixed in the lathe, then the air can be filtered and regulated in pressure of 320 kPa.

In this cooling/lubrication system it was used the fluid of the Quimatic brand.

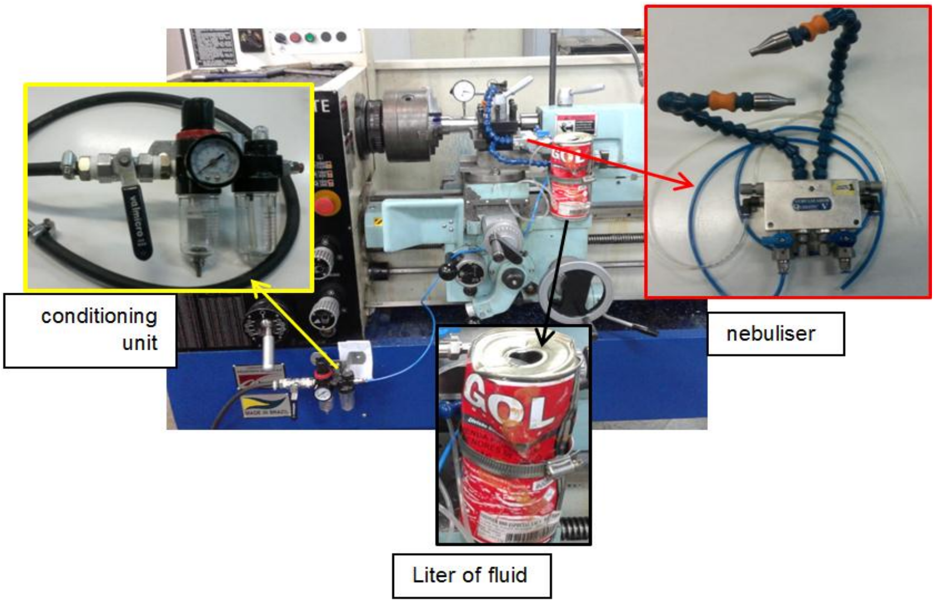


Figure 3 - Fitting of the MQL System and the components used

The surface finish of the machined specimen was evaluated with the use of a rugosimeter Mitutoyo SJ-210 model.

To assess wear of the cutting tool it was used a digital microscope, of the Dino-Lite brand, AM-413T model, coupled to a PC, the pictures taken had a magnification of 205*x*. The observation and measurement of the wear were made in the Dino Capture 2.0 software.

The evaluation of the chips was done similar to the tool wear, the photos were taken in the digital microscope with magnification of 205*x*, and analyzed its type, shape and color in the Dino Capture 2.0 software.

For measuring the error of form (circularity) it was used a dial indicator of the Mitutoyo brand with centesimal resolution (0.01 mm).

4. ANALYSIS OF RESULTS

4.1 Analysis of the chips

In Figure 4 the Photos of the chips are presented.

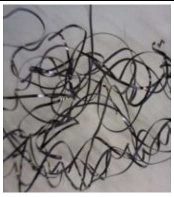
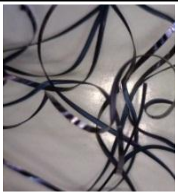
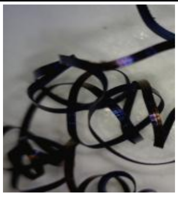
Cutting speed	Chips obtained in dry turning		Chips obtained in turning with abundant gush of fluid		Chips obtained in turning with MQL	
	Advance 0.05 mm / rev	Advance 0,1 mm/rev	Advance 0,05 mm/rev	Advance 0,1 mm/rev	Advance 0,05 mm/rev	Advance 0,1 mm/rev
125 m/min						
157 m/min						
196 m/min						

Figure 4 - Chip obtained in turning in the three lubrication and cooling means

It is observed in Fig. 4 that the type of chip obtained in the turning process was only the continuous chip, in factor of the machined material, SAE 1045 steel, and the machining parameters used.

About the shape of the chip the increased cutting speed and the advance tended to increase the size and entangle the chip. The machining with abundant gush of fluid decreased the chip size and reduced the tangle.

According to Yamakami et al. (2006) the increase of the cutting speed promotes an increase in shear rate of the material and consequently raises the temperature in the cutting zone. And according to Zeilmann and Vacaro (2008) the highest machining temperatures are very influential in the formation of chips and may result in the formation of chips in form of strips (tapes) or tangles.

The machining with cutting fluid has characteristics such as better performance in the mechanism of formation of the chip and better ease of expulsion of the chip in the cutting region (BORNHOLD et al., 2011).

When machining with MQL there has been no change in the chip shape compared to the dry machining.

Another feature examined in the chip was its color. The predominant color in the chips was dark blue, due to the high heat, lighter coloring was observed with use of the abundant gush due to the cooling in the chip output;

The dark blue color indicates high generation of heat between the workpiece and the tool. This explains the occurrence of high shear rate of the material and, consequently raising the temperature in the cutting zone (YAMAKAMI et al., 2006).

4.2 Wear and damage of the cutting tool

This study did not aim to determine the cutting tool life in cutting parameters used but measure and analyze the flank wear of the tool in relative to the means of lubrication / cooling and make an estimate of what means of lubricating / cooling the tool worn more and which tool worn less.

Figure 5 illustrates the final flank wear of the cutting edges.

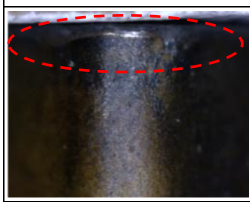
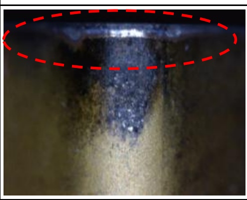
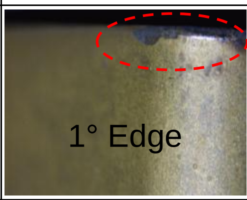
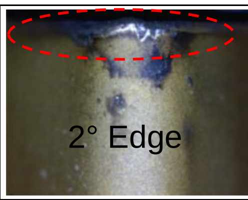
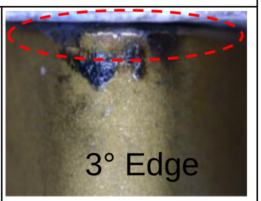
DRY	MQL	ABUNDANT GUSH		
				

Figure 5 - wear details and damage of cutting tools

Figure 6 shows the final values of flank wear of each cutting edge used.

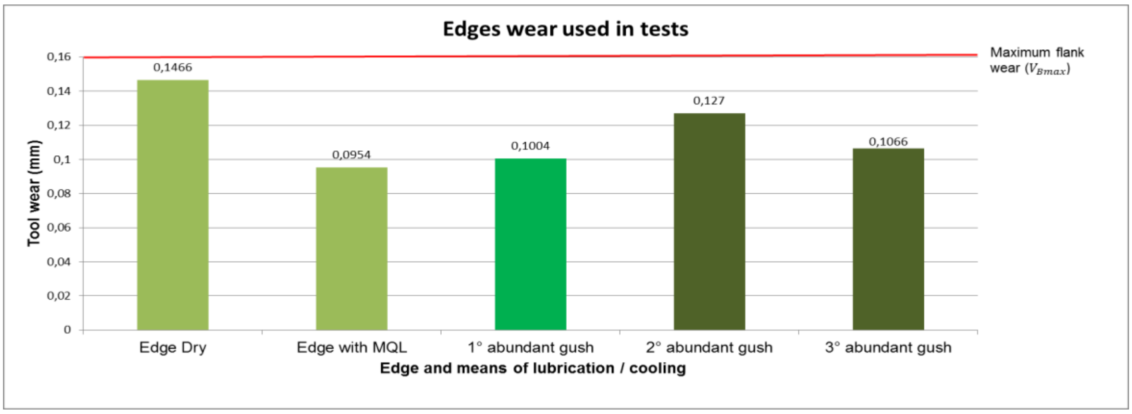


Figure 6 - flank wear of the cutting edge in the lubrication / cooling means

We can notice that when machining with abundant gush 3 edges have been used, the cause of this was the constant occurrence of chipping that damaged the edge. It is also observed that the result was a greater wear in this means of lubrication/cooling, because for the six tests three cutting edges were used and showed wear above of 0.1 mm, if added up they result in greater wear in relation to others means of lubricating / cooling used.

The cause of these chipping may be related to the thermal shocks suffered by the tool during cutting operations and the cooling that left the material harder, requiring more effort from the tool.

The use of fluid increases the thermal variations and, thus, the likelihood of cracks and chipping of the tool edge increases (LIAO, 2007; Liew, 2008; STANFORD, 2007 cited ZEILMANN et al.2009).

The turning with MQL showed the best performance for tool. After machined all parameters for this means of lubrication, the edge showed a flank wear of only 0.0954 mm, the lowest of all the cutting edges.

The abrasion and adhesion mechanisms are prevalent in the formation of flank wear (ZEILMANN; VACARO, 2008).

The lowest wear observed in MQL condition was the reduction for abrasion and adhesion caused by lubricating film obtained with minimal amounts of oil.

4.3 Circularity deviation

Figure 7 shows the results for the deviation of circularity.

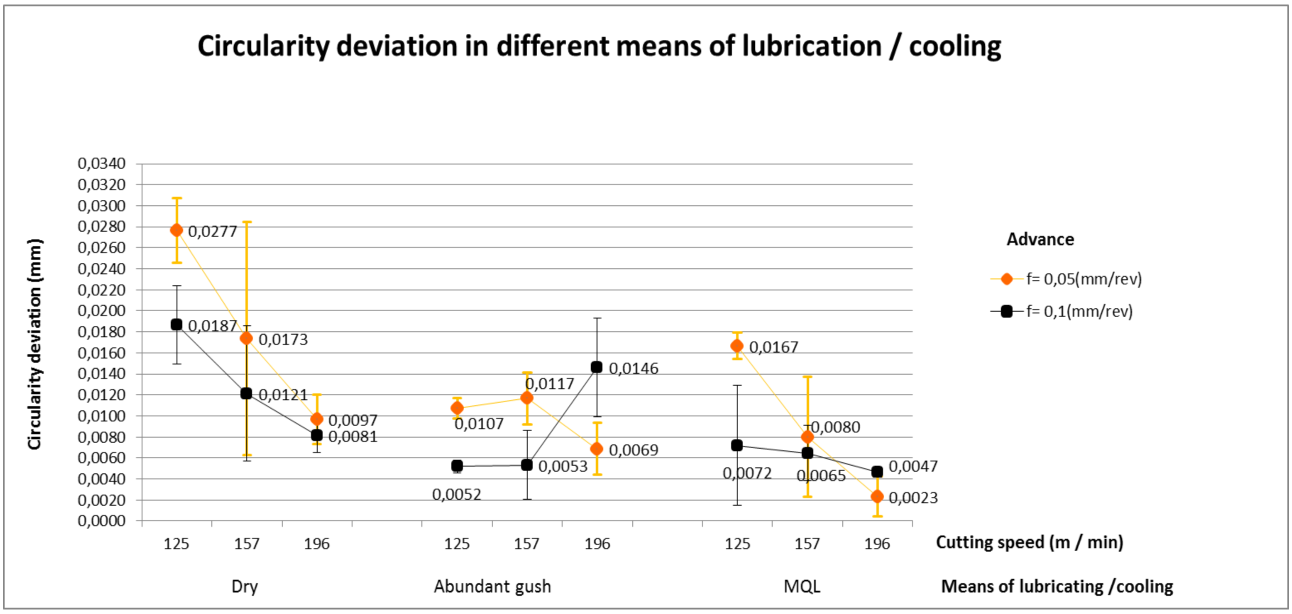


Figure 7 - Comparison of Circularity deviations from the three methods of lubricating/cooling

Figure 7 shows a trend of reduction of the circularity deviation with the increase of the cutting speed, except for the turning with abundant gush that did not show this tendency. According to Ghani & Choudhury (2002; cited BONANDI 2012) in materials with lower hardness, the process tends to become more stable with the increase of the cutting speed and a consequent reduction of vibration of the machine-support-piece set.

Regarding the advance there were best results in the advance of 0.1 mm / rev and in relation to the method of lubrication / cooling the dry machining showed the highest values of circularity deviation as 0,0277mm, 0,0187mm and 0,0173mm. It is possible to analyze the graph above to infer that the use of lubricant/coolant (abundant gush) or just lubricant (MQL) reduced the deviation of circularity.

According to Ferreira (2014) during the machining, system elements of Machine/Tool/ Fixation Devices/Piece (MTFP) are heated. This leads to thermal deformation of the system and machining errors. This heat originates from various sources, such as the cutting process, the friction between the components of the machine-tool and the power unit. It is known that the heat will be distributed among the workpiece, tool and chips and it depends on the machining conditions. With the use of lubricating means there is a reduction in the heat generated by lubricating and cooling and so reducing the circularity error. The application of certain measures such as the use of cutting fluid decreases the effects of thermal deformation of the MTFP system (DÓRIA, 2005).

4.4 Surface finish

Figure 8 shows the results for the roughness *Ra* parameter

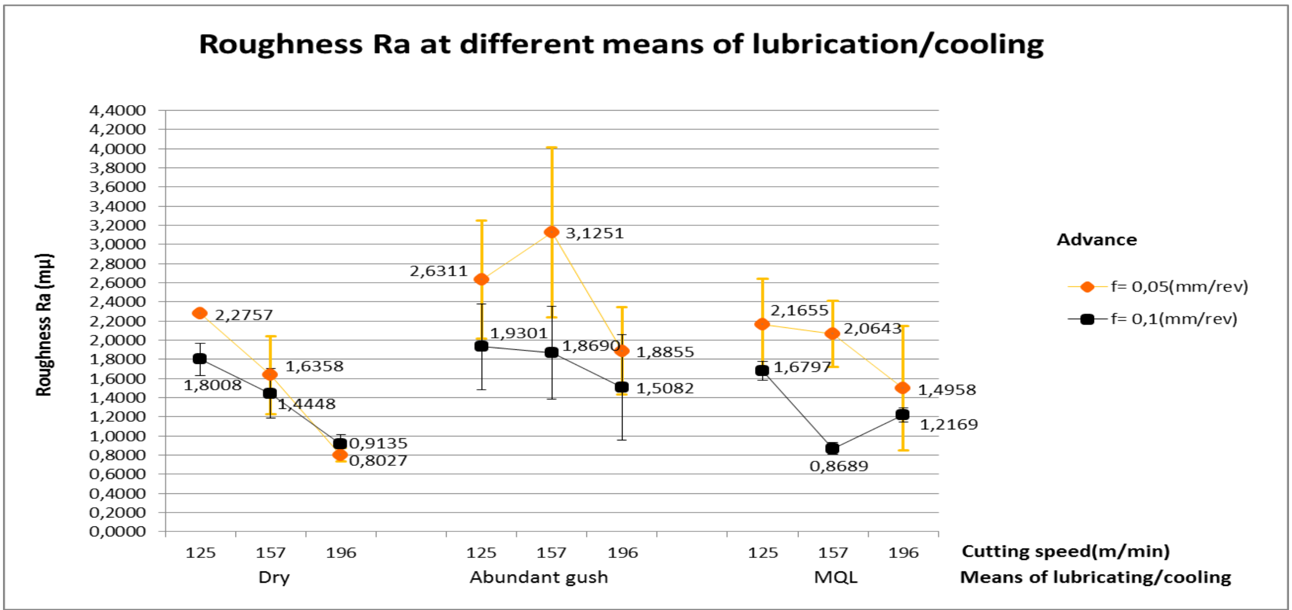


Figure 8 - Comparison of roughness Ra obtained in the three methods of lubrication/cooling

Figure 8 shows a tendency of decrease of roughness with the increase of the cutting speed.

The explanation for the reduced surface roughness with the increase of the speed is in the chip formation process. The increase in the cutting speed causes a rise in temperature in the cutting region and causes a softening of the material. However, at the same time the material in front of the cutting edge has an elevation in its mechanical strength, due to work hardening caused by a greater plastic deformation. Thus the material becomes brittle due to hardening and ductile because of the softening and facilitating the chip formation. Thus, it can be said that the chip becomes more sheared than pressed and the cut occurs more easily, improving the surface finish (PAULO et al., 2007).

It is also observed in this figure a strong relationship of roughness with the advancement, for all parameters of lubricating / cooling the advance of 0.1 mm / rev, the largest, showed lower roughness.

The Ra roughness in machining with abundant fluid was larger than in other lubrication and cooling means, each cutting speed and advance showed a higher roughness with the use of abundant fluid. The higher values of roughness 2,6311µm and 3,1251µm were obtained in this means of lubrication and cooling. The use of cutting fluid in steel reduces the temperature and makes it difficult to cut material, thus there is an increase in the cutting force and amplitude of vibration tool, generating a worse surface finish (Tedesco, 2007).

According to Micarone and Diniz (2002) the dry cutting facilitates the formation of the chip when reducing the hardness and strength of the material near the region of shear of the chip.

The lubrication with MQL obtained lower values of roughness than in machining with abundant fluid. In MQL condition while there is a deficiency of cooling in the cutting zone, the heat generated also has a positive effect, because the increase of the temperature in metal to be machined decreases its shear strength. The minimum lubrication is sufficient to reduce friction, while it is availed the positive effect of heat in the cutting area. This effect does not occur in the emulsion condition, since the use of the fluid in abundance prevents a significant increase in the workpiece temperature, maintaining the high shear strength of the material (ZEILMANN et al., 2009).

5. CONCLUSIONS

Based on the analysis presented in this work, it be concluded that:

The turning with abundant gush of fluid resulted in greater wear and damage by chipping in the cutting tool due to frequent thermal shocks and the machining with MQL brought the best living conditions for the tool.

The deviation of circularity decreased with the increase of the cutting speed and the dry machining showed higher values of circularity deviation due to the generated heat.

The surface roughness had a tendency to decrease with the increase of the cutting speed, because of the ease in the chip formation, the advance 0.1 mm / rev showed lower values of roughness and the surface roughness increased with abundant gush of fluid.

The lubrication with MQL is feasible, showing the best results for the tool life, circularity, roughness and being an environmentally correct technique.

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7. RESPONSIBILITY NOTICE

The author Eliézer Reis Teixeira and Dr. Janaina Fracaro de Souza Gonçalves are the only responsible for the printed material included in this paper.