STUDY OF THE MACHINING BY TURNING OF THE NICKEL SUPER ALLOY PYROMET A31: FLOOD FLUID X MQL

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Abstract*. The increasing competition between companies in the world market makes the same seek processes that ensure lower costs allies to high productivity and high quality product. Thus the great industrial and technological development has increased the search for machining processes that promote, for example, great capacity of chip removal, reduction of damage and tool wear and minor impacts to the environment. Regarding nickel alloys, they have an extremely important role in the automotive and aeronautics industry among others. The nickel super alloy studied is the Pyromet A31for having mechanical strength and corrosion resistance at temperatures of approximately 815 °C, for both two conditions of the alloy were used hot rolled and hot rolled followed solubilization. The objective of this work is to study the influence of the application of cutting fluids in turning, and thus promote the optimization of machining this super alloy. The super alloy was turned using various machining parameters: cutting speed, feed rate, depth of cut, Minimum Quantity Lubrication (MQL), Flood Fluid, cutting tools with coating and without coating. After turning chip samples were obtained, was measured roughness of the material, volume of removed chip, cutting length and held macrostructural analyzes and of lifetime of the tools used in order to detect possible wear. In this work it can be seen that in general the application of coating cutting tools present greater cutting lengths when compared to without coating. Regarding the use of MQL noted that despite of ecologically correct not promote cutting lengths sufficient to viable its application, however when it is necessary lower values of roughness the MQL showed efficient.*

Keywords*: Turning, Minimum Quantity Lubrication, Flood Fluid, Nickel Super Alloy.*

1. INTRODUCTION

The development of metallic materials is intimately associated to technological advances. The necessity of materials to be more resistant to wear, corrosion/oxidation and tougher, has been the impulse for the research of many materials. Originally, the stainless steels and alloyed steels were used, but the necessity of an operation at higher temperatures, encouraged the development of the refractory alloys or “superalloys”.

The use of the nickel based alloys in the aeronautical and rocket engineering field is mainly because of their good performance at high temperatures, which is given for some of its intrinsic characteristics, such as having a high mechanical strength at elevated temperatures, a high resistance to fluidity, a high resistance to fatigue, and corrosion resistance (EZUGWU et al, 1999) (SILVA, 2002). The nickel alloys have a chemical composition containing high levels of alloying elements, which are responsible for their mechanical and thermal properties, but these characteristics make its machining excessively difficult, causing some problems during the process (SILVA, 2002).

The main difficulties in machining these alloys can be summarized as (EZUGWU et al, 2003): High strength and hot hardness; the austenitic matrix of the nickel alloy promotes a fast hardening; the presence of hard carbides and abrasives in the microstructure; the low thermal conductivity, and the weldability of the workpiece material in the cutting edge of the tool.

It is important to emphasize that the change in the surface, as the residual stress during the machining, can result in unfavorable distortions to the workpiece. For this reason, special care must be taken to ensure the lifetime of the tool, the workpiece surface integrity, and the control of the main machining parameters (SILVA, 2002). Therefore, to obtain satisfactory machining conditions, it is necessary to have a good understanding of the microstructure of the involved materials, the effects about the behavior of the cutting tools, and on the efficiency of the utilized machining processes (VIGNEAU, 1997).

According Ezugwu et al (2003), the use of conventional refrigeration (Flood Fluid) is not way to the improvement of conditions of the machining of superalloys since the Refrigerant is unable to reach the cutting zone due to the formation of steam that prevents the penetration of refrigerant into the high temperature zone. The flow of chip can still prevent access by refrigeration in the cutting zone. The administration of refrigeration directly in the cutting zone is required to ensure an efficient and economic machining of the superalloys. High pressure of refrigerant, cryogenic refrigeration and Minimum Quantity Lubrication - MQL are techniques used for achieve this goal.

The use of MQL is a technology developed which consists of administering small quantities of lubricant in the tool-chip interface during the machining. In this technique are used about 6 to 70 ml/h of refrigerant/lubricant against 300 to 4000 ml/min. used in abundant lubrication (Derflinger et. al., 1999). The technique of MQL involves the application of a small quantity of water and soluble oil, used through of compressed air which propels the solution by means of a jet sprayed in the cutting edge from tool. This technique has demonstrated successful in grinding processes, milling and turning (BRINKSMEIER et. al., 1999).

2. MATERIALS AND METHODS

2.1. Materials

The Pyromet A31superalloy, used was produced by the Hot rolling process with final hardness between HRC 41.5 and 42.5 and under a hot rolling condition followed by a solubilization treatment (1040 °C for 1h with air-cooling) and aging (780 °C for 4 h with air-cooling), with hardness varying between 36 to 38 HRC. Tab. 1 below shows the composition of the alloy used in the tests.

Table 1: Nominal composition of the nickel Pyromet A31superalloy (Internet: Cartech)

COMPOSITION	Ni	Cr	Fe	Ti	Al	Nb	Mn	Si	S	Mo	B	P	C
PYROMET 31V (SAE HEV8)	57,0	22,7	Rem.*	2,3	1,3	0,85	0,2 Máx.	0,2 Máx.	0,015 Máx.	2,0	0,005	0,015 Máx.	0,04
*Rem.: Remaining													

The workpieces dimensions were: Length = 185 mm and Diameter = 52 mm.

The tools used in the tests as indicated by the manufacturer (Sandvik) for superalloys machining, were coated hard metal pads TNMG 160408-23 Class S15 (GC 1005) and uncoated hard metal pads TNMG 160408-23 Class S15 (H13A). Coated tools (Sandvik GC 1005) were chosen because they present good resistance against plastic deformation. The tool uncoated H13A was selected to combine good abrasion resistance with good toughness in the superalloy turning (Sandvik, 2005).

The tests were performed on a CNC MACH-9-Centur 30S, 25 to 3500 rpm, with power of 7.5 CV, ROMI.

The cutting fluid used for abundant lubrication was the Lubrax OP-38-EM that consists in an oil emulsion of naphthenic base. The cutting fluid flow during the tests was at approximately 4.8 liters/minute. For the tests developed with the Minimum Quantity Lubrication (MQL) technique the Accu-lube equipment was used, which is manufactured by ITW Chemical Products Ltd. The vegetable-based lubricant LB 1000 was used according to the manufacturer's instructions. The flow and pressure for the test were adjusted to 5 ml/h and 5 bar, respectively. The nozzle of the MQL equipment was put about 30 mm from the tool and directed to the rake face.

2.2. Methodology

The process used in the tests was the cylindrical external turning that were conducted so that, at each pass realized in in the workpiece, it was removed from the lathe, its diameter and tool wear were measured, and chip samples were collected for analysis. The criterion chosen for the ending lifetime of the tool was the maximum flank wear (VB_{Bmax}), which equals 0.5 mm.

The material tested will be indicated in the case of the hot rolled alloy that passed by solubilization followed by aging as the alloy solubilized, while the other one that did not receive thermal treatment will be simply called as hot rolled alloy.

The parameters used for the machining are showed in the Tab. 2.

Once the end of the tools lifetime is reached (VB_{Bmax} = 0.5 mm), they were identified and subsequently forwarded to the Zeiss stereoscope to check the wear values measured by graduated magnifying glass.

Table 2: Parameters used for the machining.

Lubrication	Alloy Conditions	Vc (m/min)	f (mm/rot)	ap (mm)
Abundant	Hot rolled	75	0.12	0.8
			0.15	
			0.18	
		90	0.12	
			0.15	
			0.18	
	Solubilized	75	0.12	
			0.15	
			0.18	
		90	0.12	
			0.15	
			0.18	
MQL	Hot rolled	75	0.15	
		90		
	Solubilized	75	0.12	
		90		

2.3. Preparation of the Material

In this study the samples were embedded with hard epoxy resin of high resistance so that they could be prepared by sanding and polishing with subsequent attack, so that finally were obtained its micrographs. The sanding occurred with SiC sandpapers of particle sizes 100, 220, 320, 400, 600, 1000, 1200 and 2000. Thereafter, the polishing was made with OP-S Suspension, and then made the etching. The proportion of reagent is defined in Eq. (1):

$$HCl + HNO_3 + H_2SO_4 \text{ (proportion 92:3:3 respectively)} \quad (1)$$

The best results were obtained with 35 seconds of etching at 26 °C. For the revelation of the microstructure, the method of etching was immersion. The samples were analyzed by the Scanning Electron Microscope - SEM and for the constituents to be identified and quantified using the EDS (Energy Dispersive Spectroscopy).

3. RESULTS AND DISCUSSION

In the graph of Fig. 1 is presented a comparison between the results obtained for tool life in the machining with Minimum Quantity Lubrication - MQL and Flood Fluid. In order to optimize the analysis were taken only the best valuesobtained considering tool life in the two cutting speeds used and with the two types of tools. If found satisfactory results, additional tests would be performed in the remaining parameters. When used MQL were analyzed only parameters which during use Flood Fluid showed better overall performance.

On the results noted by Silva (2002) in the machining of Inconel 718 alloy using high-speed cutting with PCBN tools (CB7050), the use of MQL showed great effectiveness in the category cutting force and temperature compared for dry machining. However, there is no indication on the results obtained in regarding lubrication abundant.

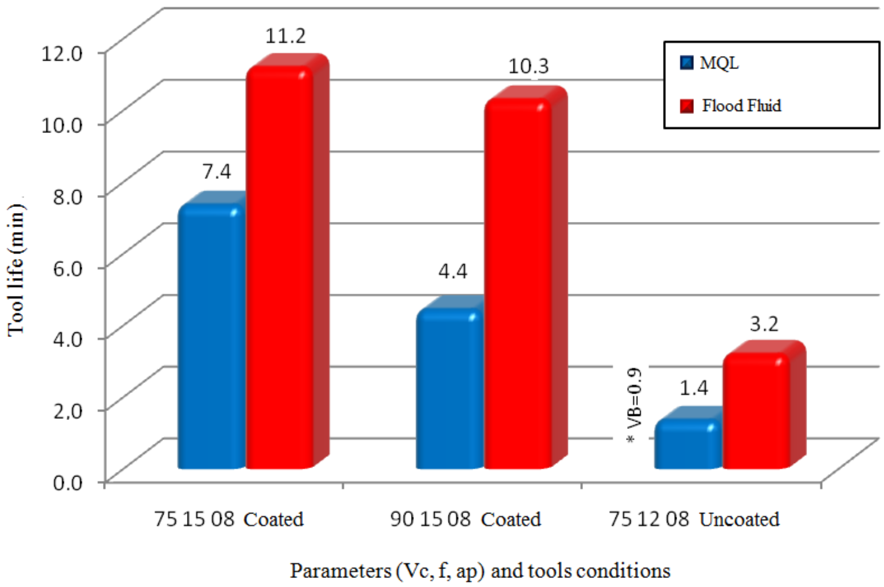


Figure 1. Tool life in machining of the hot rolled alloys with use of coated and uncoated tools using MQL and Flood Fluid.

Under the conditions used in this work, the MQL did not show better results than those obtained with abundant lubrication seen to have achieved, in some cases VB values above the maximum only in the first pass of the tool, hindering even a fair review of tool life and chip volume removed.

The Fig. 5 shows the tool life for nickel alloy solubilized in the two lubrication conditions comparing the two best lives obtained for a speed of 75 to 90 m/min for coated tools. As will be noted later in in Fig 5, 7, 9, 10, 11, 12 and 13 were not used uncoated tools for solubilized alloy that is justified by the fact of the tool has not achieved satisfactory results during testing. This is due to high abrasion of the alloy solubilized which damaged the uncoated tool at high speed making it impossible the measurements of the response variables for the parameters used, leaving a further study of the best parameters for this condition. In the alloy solubilized, the heat treatment provides a more carbon precipitation in the form of complex carbides "$M_{23}C_6$" and "M_6C" intragrains and on the grain boundaries, as provided in the literature (ASM HANDBOOK, 2005; EZUGWU et al. 1999; ZITNANSKY, 1998).

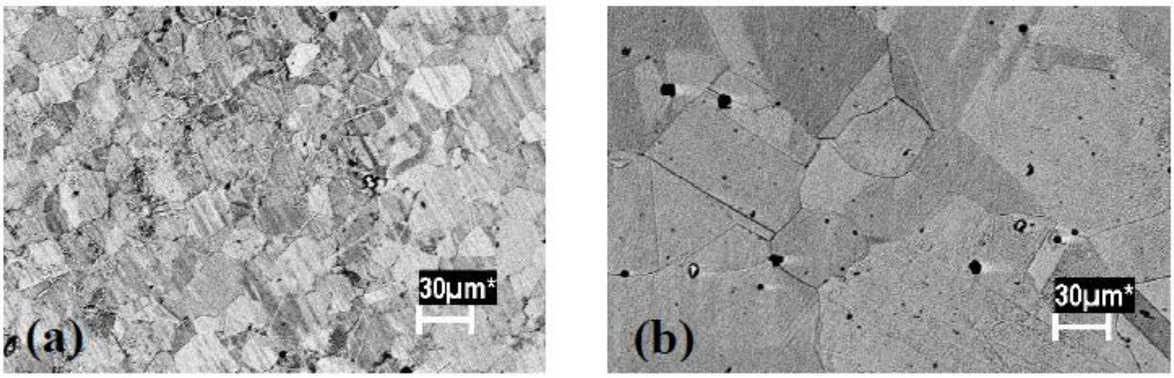


Figure 2. Scanning electron microscopy of alloys: (a) hot rolled and (b) solubilized

Through a higher magnification image, performed in SEM and presented in the Fig. 2 and 3, one can visualize in greater detail the particles of metal carbides present in the nickel alloy. In Fig. 4, through the EDS analysis, it was possible identify chemical compositions of the intragrains particles in the solubilized alloy being the particles with lighter contour indicated by (a) classified predominantly niobium carbide and titanium carbide and the Darker (b) are constituted by carbides complex with the chemical composition presented in Tab. 3.

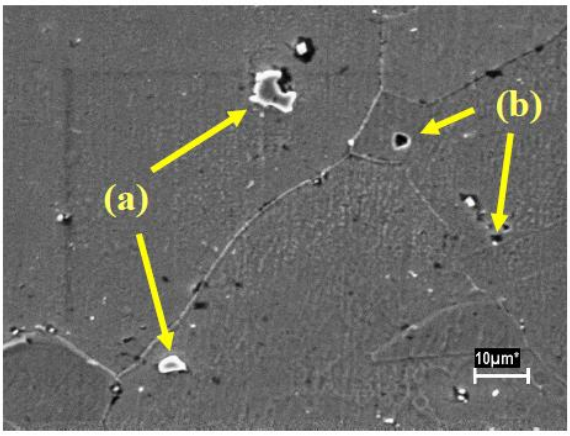


Figure 3. Scanning electron microscopy of nickel alloy Pyromet A31solubilized: a) niobium and titanium carbide and b) complex carbides.

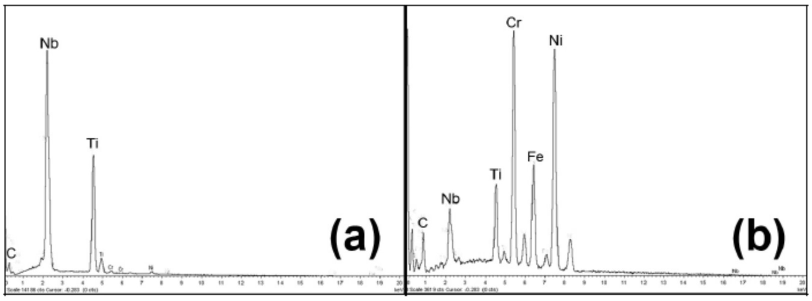


Figure 4. Chemical analysis by EDS (energy dispersive spectroscopy) of the particles of Pyromet A31alloy: (a) clear points and (b) dark spots.

Table 3. Chemical composition in weight of the superalloy Pyromet® 31V: (a) clear points and (b) dark points

Element	Atomic Number (Z)	% in weight (clear points)	% in weight (dark points)
C	6	23.33	13.24
Ti	22	26.87	5.38
Cr	24	0.69	21.14
Fe	26	--	12.70
Ni	28	1.24	42.76
Nb	41	47.87	4.77
Total	--	100.00	100.00

Due to insufficient penetration of the lubricant, resulting in a high coefficient of attrition and a low refrigeration in the piece-tool interface, occasioned a high tool wear leading to a premature failure, where in some cases was not able to remove even half of the volume of chip obtained with abundant lubrication.

It is noteworthy that, due to the small area of operation of the air/oil flow in the system MQL, the positioning of the sprinkler nozzle can affect significantly the capacity of refrigeration/lubrication and consequently the levels of wear, temperature and volume of chips.

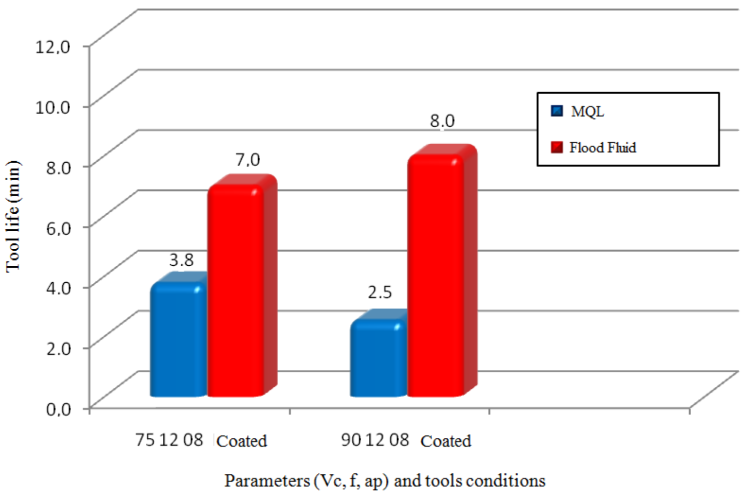


Figure 5. Tool life in Solubilized alloy with use of coated tools using MQL and abundant lubrication.

In the graph of Fig. 6 is presented a comparison between the results obtained for the volume of chips removed when machining with Minimum Quantity Lubrication - MQL and Flood Fluid, for hot rolled alloys.

Analyzing the volumes of chips removed can be observed the same tendency of better results when was used the abundant lubrication in relation to the MQL.

For speed of 90 m/min lubrication abundant made it possible a chip removal above 130%.

In the best condition of machining with uncoated tool (75-12-08) was obtained volumes higher than 180% in regarding the use of the technique with MQL, even knowing that the volume removed was for a VB (0.9 mm), exceeding the limit of 0.5 mm in the first pass.

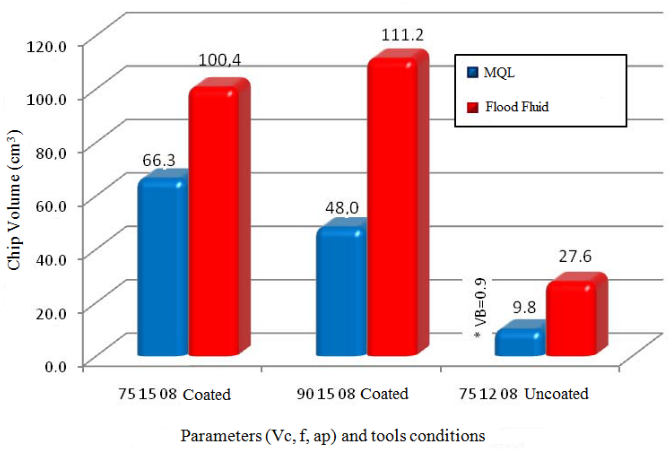


Figure 6. Volume of chips removed in hot rolled alloys using MQL and abundant lubrication.

In Fig. 7 shows the results obtained for the volume of chip removed in nickel alloy solubilized in the two lubrication conditions, comparing the techniques of lubrication and refrigeration for the two best lives obtained, speed for 75 to 90 m/min when machined with Flood Fluid.

The solubilized alloy did not show result different from that observed in the alloy hot rolled, which was larger chip volume removed for abundant lubrication.

The machining with MQL in the speed of 90 m/min. was well more aggressive than in the lowest speed, because in this case the quantity of chip removed was less than one third of that obtained with conventional technique lubrication.

The explanation for as small volume of material removed can be related to greater amount of heat generated in the machining with a speed of 90 m/min associated with increased abrasion of the solubilized alloy which, without an efficient lubrication and refrigeration of the tool-chip interface and tool-work piece, elevates considerably the temperature at the tip of the tool causing it to wear premature.

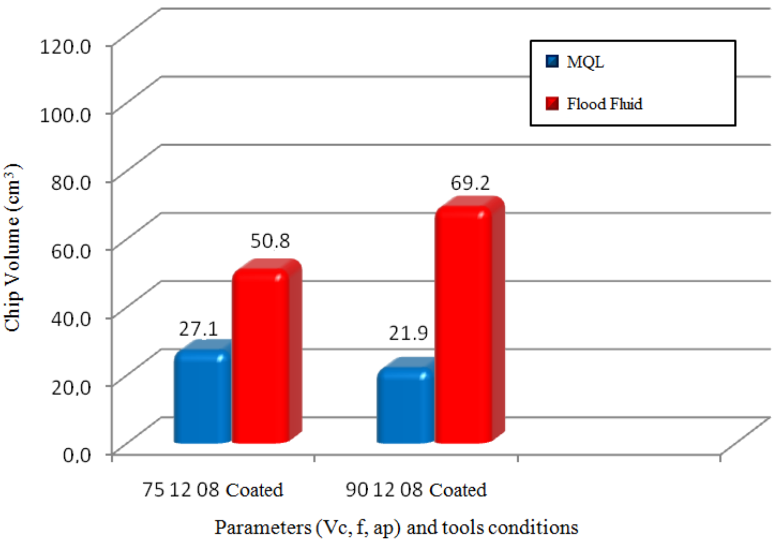


Figure 7. Volume of chips removed in Solubilized alloy using MQL and abundant lubrication.

In the analysis between the roughness values obtained between the two systems of lubrication and refrigeration used it is clear that, despite the low volume of chips removed, the level of roughness using MQL was better in practically all tests performed.

In Fig. 8 and Fig. 9 shows the comparison between the roughness Ra, at the end of machining, hot rolled and solubilized alloy respectively, for two types of lubrication and refrigeration.

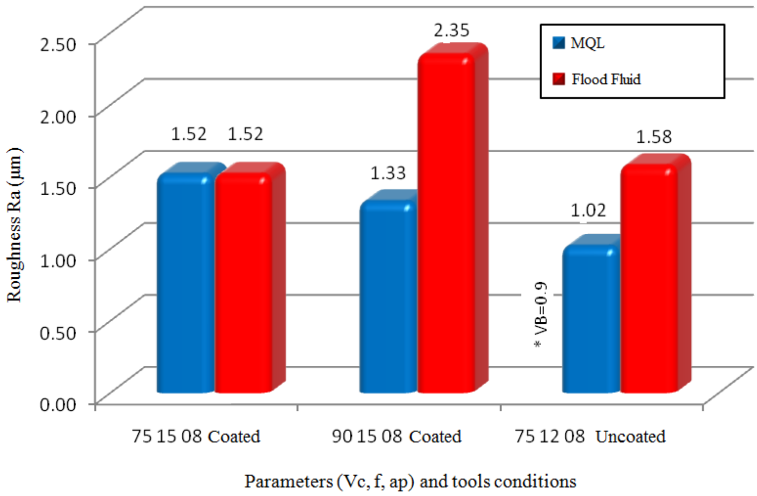


Figure 8. Average roughness (Ra) in hot rolled alloys with use of coated tools and uncoated using MQL and abundant lubrication.

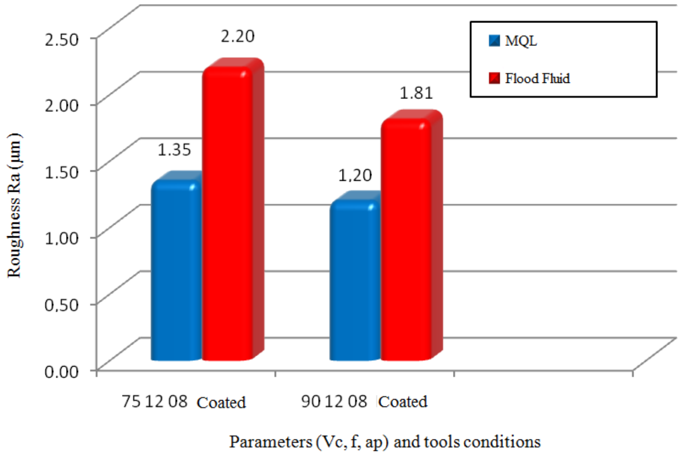


Figure 9. Average roughness (Ra) in solubilized alloys with use of coated tools and uncoated using MQL and abundant lubrication.

According to the graphs presented perceives that for the nickel alloy Pyromet® 31V, the use of cutting tools recommended by the fabricant and used In these experiments, in the cutting conditions established, the system performance MQL cannot yet be considered satisfactory.

Despite the advantages of reduction in the lubricant consumption, in the disposal costs of the material and attendance to environmental requirements, the tool life as well as the volume of chips removed are not sufficient in order to viable its application to the conditions tested.

In Fig. 10 and Fig. 11 shows the evolution of the average roughness Ra along the machined length.

Despite obtain a tool life well below using the MQL, in the test conditions performed, the values of roughness with MQL were better than in conventional lubrication condition.

Silva (2002), in the high-speed machining of the Inconel 718 and Waspaloy alloys, using several ceramic tool geometries (Al_2O_3 + SiCW and Al_2O_3 + TiC) and PCBN tools also has obtained better surfaces in the machining with the use of MQL compared to dry lubrication.

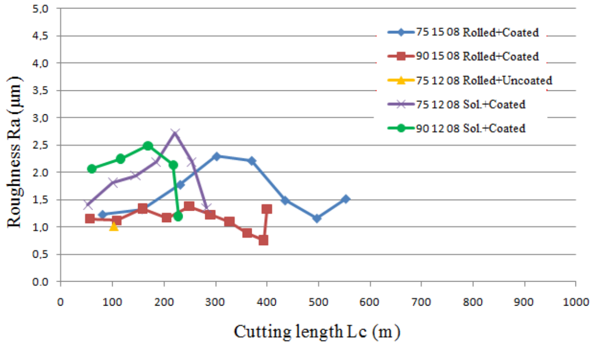


Figure 10. Evolution of average roughness (Ra) in hot rolled alloys and solubilized using MQL.

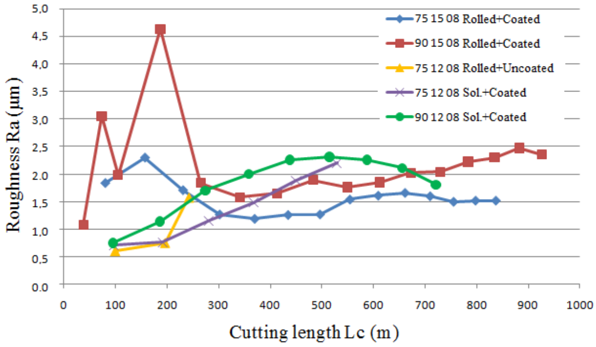


Figure 11. Evolution of the average roughness (Ra) in hot rolled alloys and solubilized using abundant lubrication.

In the graph of Fig. 11 with the parameters 90-15-08, the hot rolled alloy and coated tool, there was a very large initial variation of the roughness and starting from a certain moment there was stabilization in values presented.

This variation was not due to excessive deterioration of the cutting edge, as can be seen from the graph of the evolution of wear – Fig. 12.

The variation in the roughness may be due to a stabilization of the cutting edge during the initial stages of the operation, this stabilization cannot be confused with wear.

However, with except of the fact mentioned previously, for the other testing in the condition of abundant lubrication was not observed any atypical behavior in relation to the evolution of the values of roughness during tool life.

In Fig. 10 despite of the many variables involved in the tests presented (machined material, tool and cutting parameters), the dispersion of roughness values was always lower for MQL in relation to abundant lubrication.

This can be explained by the maintenance of the best conditions for shearing chip and decrease in deformation. Still in relation to this same graph it can be noted that in the machining of the solubilized material with the technique MQL, the phase of accommodation tool with respective increase in roughness was followed by a sharp decline in the value of Ra.

This fact coincides with the progression accentuated wear leading to the end of tool life – Fig. 12.

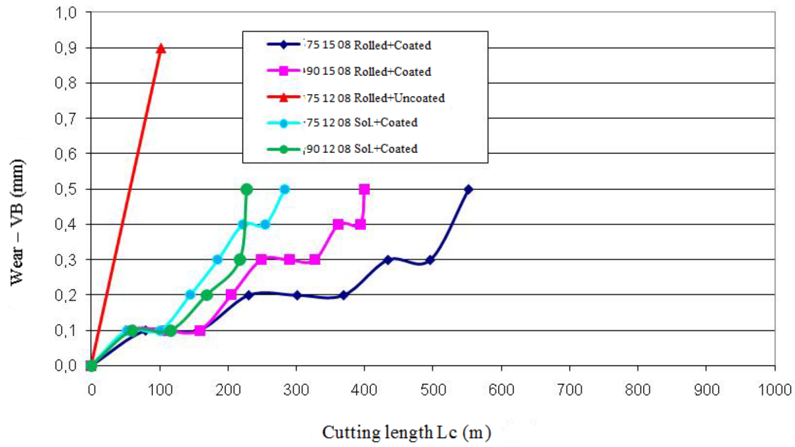


Figure 12. Evolution of flank wear in hot rolled and solubilized alloys using MQL.

In Fig. 13 shows the evolution of wear for the abundant lubrication with inclinations in the graphs much more gradual and smooth, with the exception for uncoated tool that presents accentuated inclination resulting in an end of life too fast.

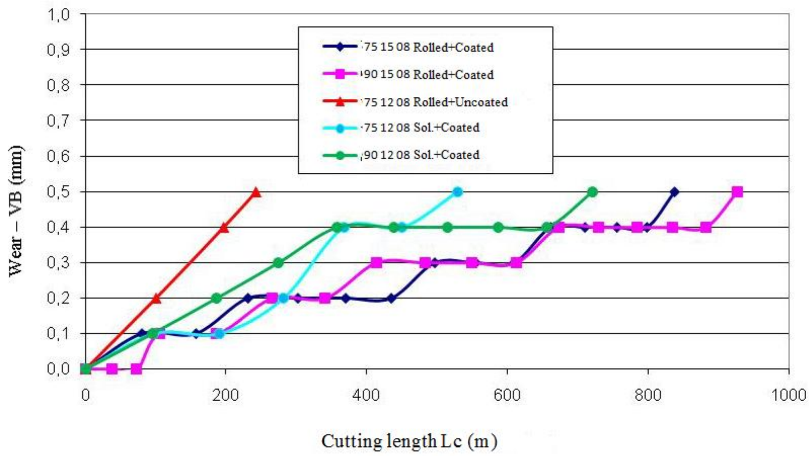
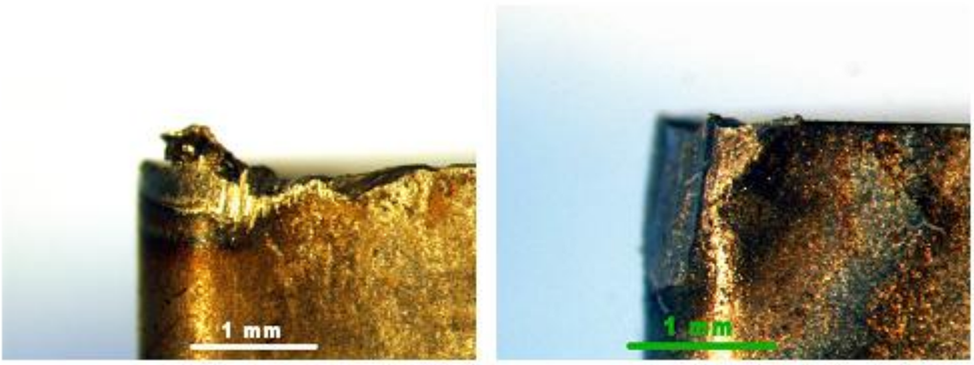


Figure 13. Evolution of flank wear in hot rolled and solubilized alloys using abundant lubrication.

The wear characteristics observed in machining with MQL are shown in Fig. 14. With the use of tools coated the wear were similar to those observed with the use of conventional lubricant, in others words, abrasion wear with formation of notch and the presence chip adhered, and wear by hammering – Fig. 14 (a). In the case of machining with

MQL using tools uncoated abrasion wear was very large, exceeding in a single pass the VB predetermined of 0.5 mm – Fig. 14 (b).



(a) Coated tool (b) Uncoated tool

Figure 14. Wear in machining with MQL: (a) hammering and (b) abrasion.

In machining with MQL for all tools coated, there was a front wear much more accentuated than in abundant lubrication in which the front wear occurred rarely, limited to the area clearance and output tool.

The reason which may explain the lower roughness using the MQL may be maintaining the best conditions for the shearing chip and decrease in deformations. The best roughness for the MQL can be a result of lower amplitude of deterioration of the cutting edge presented by these tools. Although the criterion of end of life (VB_{Bmax} = 0.5 mm) is the same for the two lubrication conditions, there is a region of the edge deteriorated largest to abundant lubrication than for MQL – Fig. 15.

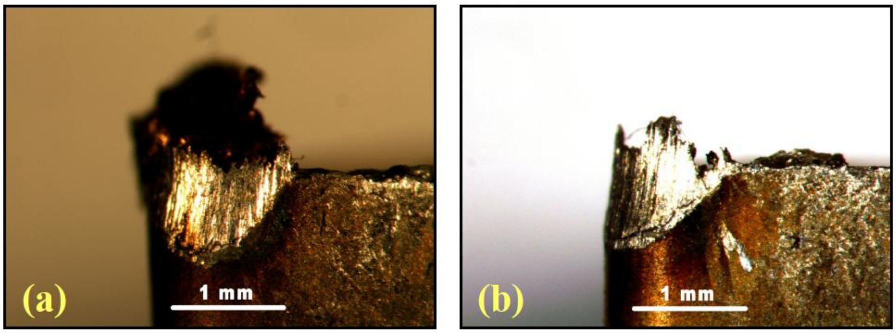


Figure 15. Wear in machining with MQL using coated tools: (a) 90-15-08 hot rolled alloy and (b) 90-12-08 solubilized alloy.

Based on the analysis of the data collected, it can be seen that the results with use of MQL are encouraging but need further research capable of explore the full potential that this technology can offer. Studies more depth should consider the effect of certain parameters in the results such as rates air-oil mixture, changes in the position of the spray nozzle, pressure suitable for the coolant so as to increase tool life and integrity of components produced with this system.

4. CONCLUSIONS

Based on the results of experiments performed with two types of tools, different types of lubrication and under the machining conditions described could conclude, for turning of nickel-based superalloy Pyromet A31(ISO UNS N07032) that:

The largest life for the tools coated using lubrication conventional were achieved with Feed rate 0.15 mm / rev. (vc = 75 m / min.) in machining hot rolled alloy and with Feed rate of 0.12 mm / rev. (vc = 90 m / min.) for the solubilized condition. In the tools uncoated the lower speed and smaller Feed rates promoted greater life;

Considering the volume of chips removed in relation to results obtained for the life of the tool, it is concluded that for machining the hot rolled alloy with coated tool and abundant lubrication, the performance of the conditions 75-18-08 and 90-15-08 proved to be best;

Despite of indicated by the manufacturer, carbide tools uncoated showed characteristics of life decreased with time well lower and a reduction of approximately 70% by volume of chips removed, compared to those coated under the same machining conditions;

In the machining of the solubilized alloy with lubrication abundant, should use the coated tool in the condition 90-12-08 that showed the best performance general in function of the tool life, volume and average roughness;

The main wear mechanisms observed in the machining of the alloys nickel with coated tools were abrasion, attrition and hammering. This was last seen in cases where there was formation of long chips and usually with Feed rates of 0.12 mm/rev.. Despite not being exactly a mechanism, but a way to localized wear, the wear notch was evident in several situations in which were used coated tools;

For the use of the MQL is implemented with competitiveness in the machining of the Pyromet A31will be needed more analysis and a series of systematic tests to identify the best combinations of parameters and machining conditions appropriate because despite the encouraging results in relation to roughness Ra obtained, the tool life and chip volume removed (50% below) are not yet sufficient in order to enable its application in testing conditions used.

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