Application of Taguchi Method in Turning Process of a Superalloy NIMONIC 80A to Improve the Surface Roughness

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ABSTRACT
The objective of this work is using a nickel based alloy Nimonic 80A optimize and control the variable response Roughness (Ra)in an external cylindrical turning using CNC Machining. Seeking the machining optimization, was used the Taguchi Method as a tool to improve this process, using the Orthogonal Array L16, operating in two levels. The machining experiments were accomplished considering the machining parameters: cutting speed, cutting depth, feed rate, kind of tool and cutting fluid. The results indicated by the Taguchi Method showed to be very useful in quality process improvement, highlighting feed rate as most significant controllable variable.

KEYWORDS
Machining, Taguchi Method, Roughness, Superalloy, Nimonic 80A

1. INTRODUCTION

The nickel alloys have a chemical composition with high content of alloying elements, which are responsible for their mechanical and thermal properties, but these characteristic makes it difficult the machining of these material.

The nickel alloys have a chemical composition with high content of alloying elements, which are responsible for their mechanical and thermal properties. The nickel alloys are typically used in the manufacture of components for aerospace applications, but these characteristic makes it difficult the machining of these material (Fox-Rabinovich et al., 2010)

Industries that manufacture components of nickel alloys based, are characterized by presenting a high cost in manufacturing of machined parts. For this reason it is interesting to reduce the machining time parts and develop more scientific approaches to select cutting tools and cutting conditions (Ribeiro et al, 2003; Jawahir and Wang, 2007).

Good results in the operation machining are related with good measurement systems, best cutting tools and cutting conditions, where these are essential elements in the planning process of the machining process. However, an experiment can be planned and for that there are techniques of experimental design to assist in the process (Wang et al. 2007; Yih-Fong, 2006).

Thus, the study propose the use of the Taguchi method as a technique of experimental design to optimize a cylindrical external turning process of the nickel based alloy (Nimonic 80A), aiming to offer more detail information about the behavior of the surface roughness of this alloy.

1.1. Nickel Based Alloy

Super alloys are characterized by a great heat resistance where according with Choudhury and El-Baradie (1998), it can be divided in three groups: nickel, nickel–iron and cobalt, as can be shown at the Figure 1.

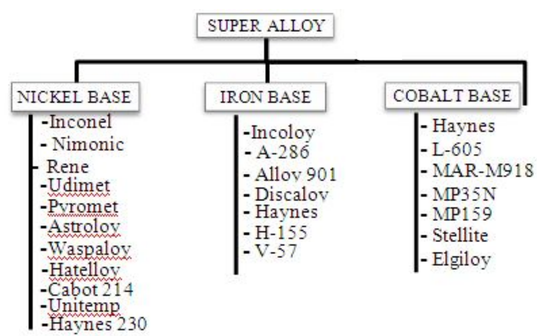

Figure 1: Classification of Super Alloys (Choudhury and El-Baradie,1998)

According to Habeeb et al (2008) and (Kamata and Obikawa, 2007), due to the very low thermal conductivity, the nickel-alloy based makes the tool face absorbs the biggest portion of heat generated at the cutting zone may cause an intensive wear rate of the cutting tools decreasing its life. For this reason, the coolant fluid is widely used in machining process, having as main objective the improvement of machining process, consequently improving surface finished and resulting in an increasing of tool life.

Ezugwu et al. (1999) said that the reason for this poor machinability of Ni-based alloys can be summarized as follows way.

* High level of strength is maintained in the machining process due to their high temperature properties;
* Work hardening occurs rapidly, contributing with the notch wear;
* Cutting tools suffer high abrasive wear, because of the carbides presents in the superalloy;
* Chemical reaction occurs at high cutting temperatures leading to a high wear rate;
* Welding adhesion of nickel alloys on the cutting tool;
* Production of chips continuous causing degradation of the cutting tool;
* Poor thermal diffusivity often generates high temperature at the tool tip.

Thesesuperalloysare characterized for having high toughness, often exhibit work hardening behavior and high adhesion caused by its austenitic matrix, that harden rapidly during the machining, becoming generally extremely difficult(Choudhury and El-Baradie, 1998; Ulutan and Ozel, 2011).
Super alloys have gone through for many transformations with additions of chromium, aluminum, titanium, cobalt, molybdenum and other elements in their structure, varying quantities to give higher performance (Ezugwu et al., 1999).

1.2. Machining Process

According to Calamaz et al. (2008) machining process is one of the oldest industrial processes and it is the most industrial manufacture of workpiece used, where is estimated that in the world the 15% percent of all mechanical components are made by machining process.
To Gaitonde et al. (2009) the machining process has been used in many applications such as the manufacture of gears, shafts, bearings, cams, forged parts, molds and dies, so that there is a significant reduction in production costs, deadlines and general improvement in product quality.
Given the wide variety of parts currently available and the increasing demand for precision machining and in high speed, the competitiveness of machining industries increases requiring more and more the demand for a robust machining process (Yih-fong, 2006).
According to Lee and Kwon (2010) to increase efficiency and productivity of the machining process, one must consider the type of cutting tool and machining parameters where the improvement of productivity and efficiency in the machining process can be obtained by process optimization.
To achieve and satisfy the increased requirements of precision products, high cutting speeds machining processes, that can be controlled the processing times, have been the output employed during the last years, where the most known example is the process on a CNC machine (Tillmann et al., 2010; Gurel and Akturk, 2007).
The CNC (Computerized Numerical Control) were initially designed to solve the High complex machining and subsequently came to help reduce unproductive (Tzeng et al., 2009).
However, to achieve good results in the machining operation are directly related to the measurements of the desired components, selection of cutting tools and cutting conditions, are essential in the planning of the machining process, once that each material can be influenced by different machining parameters and has its specific behavior(Wang et al. 2007; Yih-Fong, 2006).
The use of these machines becomes economically feasible, only when it is guaranteed the effective employment of these machines and tools during the machining process (Ribeiro, 2003). However, to discover what are the best conditions to work is necessary investigate, where it can be made using experimental procedure. For this, there are some techniques of Design of Experiments (DOE) that helps in this kind of investigations.

1.3. Design of Experiment

According to Mattos(2004), an experiment is a test or a series of tests in which the input variables of a system are manipulated to be identified the reasons for changes in output variables.
Project benefits include the possibility of experiments in improving performance in the process, avoiding trial and error to find solutions (Kleijnenetal, 2005). To (Antony etal, 2006) DOE emphasizes the development and use of regression models for predicting the process behavior under different process conditions to a certain level of confidence.
ADOE method widely spread is the Taguchi method, which for (Kishore etal, 2009) is a method that involves the orthogonal array to organize the parameters that affect the process and the levels that are diverse. This method determines the factors that affect product quality with a minimum amount of experimentation.
Taguchi developed the foundations of Robust Design introduced in the 1950s and 1960s and the application of his method in electronics, automotive, photographic and many others industries has been an important factor in the rapid industrial growth of Japanese industries (Phadke, 1989).
To Taner and Antony(2006)Taguchi method scan be use d to reduce thet ime to experiment and produce sufficient information to reduce variability and ensure a better quality product or service.
The benefits of this include the possibility of experiments in improving performance in the process, avoiding trial and error to find solutions, being considered as powerful tool for process investigation and optimization (Kleijnen et al., 2005; Xiansheng et al., 2011).
The DOE methods are more satisfactory than the try and error method, because with these methods the efficiency will be increased providing studying several factors simultaneously, showing the following general advantages(Hajjaji et al., 2010):

* more information per experiment;
* reduction of the number and cost of experiments;
* it makes possible the calculation of the interactions among variables;
* ithelps in the determination of the operating conditions in the process.

For Besseris (2008) and De Souza et al., (2011), one of the most attractive and powerful methods of the design of experiment and that have been tested for single product characteristic improvement, has been the Taguchi method, where is developed with the following steps:

* Select the output variable (response) to be optimized;
* Identify the factors that affect the output variable(s) and choose the levels of these factors;
* Select the appropriate orthogonal array that accommodates with minimum effort all considered controlling and noise factors;

- Assign factors and interactions to the columns of the array;
- Perform experiments; at this step it is important to randomize the trials in order to minimize the systematic error;
- Perform statistical analysis to analyze the results using signal-to-noise ratio (S/N) analysis and analysis of variance (ANOVA);
- Determine statistically significant factors and their optimal settings;
- Perform confirmatory experiments, if it is necessary.

According to (Rosa et al, 2009), (Chen et al, 2010) and De Souza et al., (2011), Taguchi's parameter design method normally selects an appropriate formulation of the S/N ratio and calculates the S/N ratio for each treatment. The S/N ratio is a logarithmic function used to optimize the process or product design, minimizing the variability.

There are three types of S/N ratios: nominal the best, the larger the best, and the smaller the best.

Nominal the best: S/N = 10 x Log$\left(\frac{\overline{y^2}}{\overline{S^2}}\right)$,

Larger the best: S/N = -10 x Log$\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$ and

Smaller the best: S/N = -10 x Log$\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$,

wherey_i is the response value of a specific treatment under *i* replications, *n* is the number of replications, $\bar{y}$ is the average of all *yi* values, and $\bar{S}$ is the standard deviation of all *yi* values.

2. EXPERIMENTAL PROCEDURE

Based on the analysis of the experiments and their results, it intends to guide the choice of production parameters, which will permit a smaller surface roughness possible, evaluating the best arrangement between the chosen parameters and the effect of the interaction between them.

2.1. Material of Study (Nimonic 80A)

The results were obtained from tests performed on cylindrical machining specimens with initial diameter D = 69 mm and initial length Lf ranging from 180 to 190 mm, as shown in Figure 2.

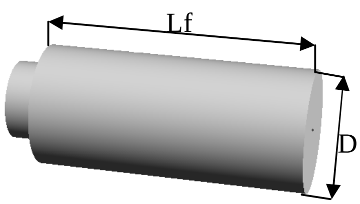

Figure2-Representationofthe workpiecefor useinturning operations

For the tests was used a nickel base alloy, Nimonic 80A the chemical composition is specified in Table 1.

Table 1 - Chemical composition of nickel-based alloy used in this work.

Composition	Ni	Cr	Cu	Fe	Ti	Al	Co	Mn	Si	S
NIMONIC 80 A	Balance	20,0	0,05	0,75	2,35	1,25	1,0	0,35	0,35	0,007

Source: Villares Metals Catalog

The chemical composition with high content of alloying elements provides excellent mechanical and thermal properties to super alloys, but it have an austenitic matrix becoming difficult the machining of this materials (Choudhury and El-Baradie, 1998).

Some physical properties of the Nimonic 80A is given by the Table 2 and Table 3.

Table 2: Physical Properties of the Nimonic 80A

Density, g/cm^3..8.19

Melting Range, ^{0}C 1320-1365

Magnetic Properties

Mass Susceptibility ....5.85 x 10^{-6} at 1000 gauss

Volume Susceptibility ....4.78 x 10^{-5} at 1000 gauss

Magnetic Permeability.........1.000601 for 200-2000 oersted

Source: Special Metals

Table 3: Others Physical Properties

Temperature	Specific Heat	Thermal Conductivity	Electrical Resistivity*	Torsional Modulus**
°C	*J/kg °C*	*W/m •°C*	*Relative Resistance*	*GPa*
20	448	11.2	1.000	85
100	469	11.6	1.008	84
200	494	14.4	1.023	82
300	519	16.1	1.040	79
400	548	17.8	1.064	77
500	573	19.4	1.073	74
600	599	20.8	1.064	70
700	628	22.3	1.064	67
800	653	24.5	1.057	64
900	678	26.5	1.032	58
1000	703	28.4	1.017	53

Source: Special Metals

*124 μΩ cm (746 Ω/circ mil ft) at 20°C (68°F)

** Cold rolled sheet (4 casts). Heat treated 2-3 minutes/1150°C (2102°F)/ fluidized bed quenched + 20 minutes/ 1040°C (1904°F)/air cooled + 4 hours/750°C (1382°F)/air cooled.

This alloy is classified as superalloy, being widely used in automotive exhaust valves mainly because of their largeheat resistancetoawide temperature range.

2.2. Input Variables

The cutting parameters used for the tests and the criterion for the tools life have been defined based on work visas in the literature and manufacturers' recommendations.

For Darwish (2000) the surface roughness is one of the most important factors in evaluating the quality of machining operations, and the parameters that most influence on surface finish quality are: speed, feed, depth of cut, tool geometry.
An important factor to be considered is the kind of tools, which in the present study was utilized two kinds of tools, which are:

- TNMG160404R-UX TP2500: Its feature a wide range of turning applications in both stainless steel and is also a good choice for cast iron due to its high wear resistance and edge strength.
- TNMG160404R-UX CP250: Has high toughness and is recommended especially in high temperature resistant alloy, ie the superalloy such as Nimonic 80A.

The representation of the inserts used in turning tests can be seen in Figure 3.

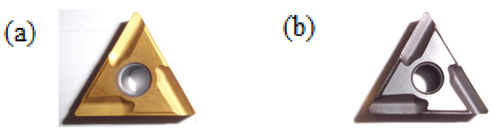

Figura 3: Representation of the two kinds of the machining tool used, (a) CP 250 e (b) TP2500

The material type was considered as the way of the material was processed, being considered that the superligaNimonic 80A in this present study was processed in two different ways: Solubilized and Hot Rolled. It typical microstructure can be seen in the Figure 4.

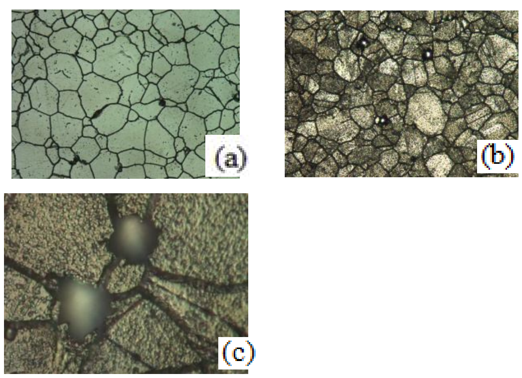

Figura 4: Microstructure representation of the Nimonic 80A in (a) Hot Rolled magnificated200x, (b) Solubilized magnificated 200x and (c) Solubilized with magnification of 1000x showing the carbide among the grain contour.

In order to optimize the process of turning to evaluate the performance of the surface finish must be considered the following parameters that can be seen in Table (3).

Table 3 – Machining parameters with its Respective Levels

	Level 1	Level 2
Cutting Speed (A)	75 m/min	90 m/min
Feed Rate (B)	0,12 mm/revol.	0,18 mm/revol.
Cutting Depth (C)	0,8 mm	1,6 mm
Tools (D)	TP2500	CP250
Environment (E)	MQF *	Abundant
Material Type (F)	Solubilized	Hot Rolled

*Minimal Quantity of Fluid

2.3. Taguchi Technique

The sequence of experiments with the combination of factors and levels is determined by an orthogonal array of Taguchi. This array will determine the number of experiments to be performed, ensuring that all levels of all factors will be tested an equal quantity. The appropriate array is selected according to the number of factors, levels and resolution intended.
In this case, for 3 factors at two levels was selected L8 orthogonal array. This array includes the implementation of eight runs showed on the Table 4.

Table 4: Orthogonal Array L16 proposed by Taguchi

Number of columns, position of the factors, interactions and levels													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**14**	**15**
	F	**A**	**AF**	**B**	**BF**	**AB**	**ED**	**D**	**DF**	**C**	**CF**	**EF**	**E**
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	2	2	2	2	2	2
3	1	1	1	2	2	2	2	1	1	1	1	2	2
4	1	1	1	2	2	2	2	2	2	2	2	1	1
5	1	2	2	1	1	2	2	1	1	2	2	2	2
6	1	2	2	1	1	2	2	2	2	1	1	1	1
7	1	2	2	2	2	1	1	1	1	2	2	1	1
8	1	2	2	2	2	1	1	2	2	1	1	2	2
9	2	1	2	1	2	1	2	1	2	1	2	1	2
10	2	1	2	1	2	1	2	2	1	2	1	2	1
11	2	1	2	2	1	2	1	1	2	1	2	2	1
12	2	1	2	2	1	2	1	2	1	2	1	1	2
13	2	2	1	1	2	2	1	1	2	2	1	2	1
14	2	2	1	1	2	2	1	2	1	1	2	1	2
15	2	2	1	2	1	1	2	1	2	2	1	1	2
16	2	2	1	2	1	1	2	2	1	1	2	2	1

*****Empty Column

For the allocation of the factors in its respective columns within the L16 experimental arrangement shown in Table 4, Figure 5 that represents the linear graph was used with the purpose to show which columns should be allocated factors as well as its possible interactions.

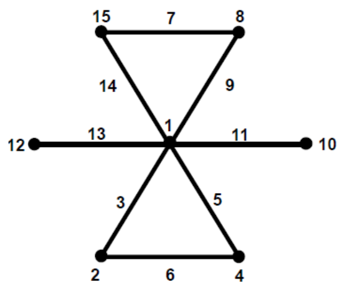

Figure 5: Linear graph of the orthogonal array L16

Where ● Factor Column and / Interaction Column

2.4. Experimental Plan

The experimental procedure was carried out at Materials and Technology Department (DMT) at São Paulo State University - UNESP. The tests were kind of external cylindrical turning as can be seen in the schematic of Figure (6), thus being conducted in a CNC lathe CENTUR 30S, trademark ROMI 25 to 3500 rpm, with power of 10 kW.

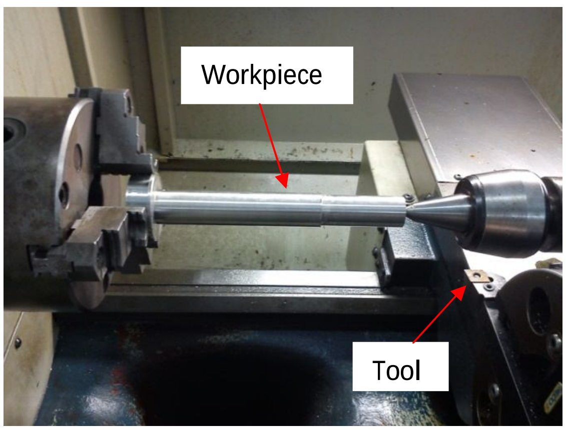

Figure 6 – Scheme of the test for external cylindrical turning

The cylindrical turning process is the process in which the tool moves a second path parallel to the main axis of rotation of the machine. The whole process was conducted in cycles where each cycle was ended when reached maximum feed length (Lf) Figure2, where after made it, the workpiece were taken out of the lathe and analyzed the surface roughness. The surface roughness was evaluated using a roughness tester Mitutoyo Surftest-301.
The duration of all trials were conditioned to the flank wear of tools, which provide study of the roughness behavior among all the tests. The experiments were driven to the point where the tool wear reached 0.5 mm, where were measured from a magnifying glass (8x) graduated in 0.1 mm. If the tool wear did not reach a value of 0.5 mm, the experiment was restarted.
To study the tools were used the TNMG160404R-UX CP250 which has higher toughness and is recommended especially in high-temperature alloys (superalloys) and TNMG160404R-UX TP2500 that has as characteristic of a wide range of turning applications in both steels stainless steel, is also a good choice for cast iron due to its high wear resistance and edge strength.
In the experiments were used a cutting fluid designed to meet the machining operations for ferrous and aluminum alloys, LUBRAX OP 38 IN, being used in abundant condition. This fluid consists of a micro-emulsion of 10% concentration in water. This coolant contains in its composition a mixture of mineral oils, esters, amides boric, surfactants, biocides and defoamers. The tests with the minimum quantity of fluid were performed with the coolant LB1000 - ITW, which is basically a mineral oil.

3. ANALYSIS AND DISCUSSION

The experimental procedure was conducted using two replicates for each experiment, considering that each replication represents the mean of a sample to Ra (μm), which was made using three measures in three different points of the work piece.
Using the cutting parameters in Table 3 and performing the experiments under the conditions defined in the Table 4 of the Taguchi´s orthogonal array, was made the Table 5, where was observed the results for surface roughness (Ra).
The Table 5 showsthe results of testsofcylindrical turninginrelationtoroughness.

Table 5 –Experimental data for Surface Roughness

Run	F	A	B	D	C	E	Ra1	Ra2
1	1	1	1	1	1	1	1,88	1,74
2	1	1	1	2	2	2	1,51	1,93
3	1	1	2	1	1	2	3,32	3,73
4	1	1	2	2	2	1	2,4	3,08
5	1	2	1	1	2	2	1,39	1,73
6	1	2	1	2	1	1	1,66	1,46
7	1	2	2	1	2	1	3,85	4,52
8	1	2	2	2	1	2	2,25	2,51
9	2	1	1	1	1	2	3,36	2,35
10	2	1	1	2	2	1	1,4	1,57
11	2	1	2	1	1	1	2,51	2,92
12	2	1	2	2	2	2	5,77	4,52
13	2	2	1	1	2	1	2,2	1,54
14	2	2	1	2	1	2	1,38	0,91
15	2	2	2	1	2	2	4,04	3,95
16	2	2	2	2	1	1	3,64	4,01

The results obtained from the Taguchi experimental array L16 shown in Table 6 and with the aid of statistical software Statistica 7.0 was possible to perform a graphical representation of the factors effects over the response variable Ra (μm), as shown in Fig. 7.

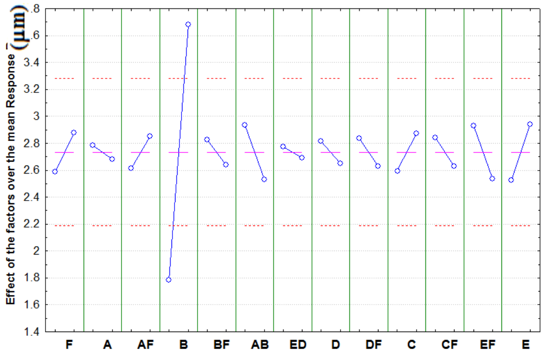

Figure 7: Effect of the factors over the surface roughness

In Fig. 7, the factor B (feed rate) stands out clearly as the dominant parameter of the process, being observed that there is a drastic increase in the variable response roughness, with the increasing of the feed rate, where can be seen that this factor is the only one to prove important in this process, overcoming the barrier of 2*σ, being σ given as the standard deviation.

According to Bouacha et al. (2010), this result was expected, as is well known that the theory, the surface roughness can be predicted and assessed in of the feed rate and of the tool radius, as the angle of attack is not being tested and are the same for both tools, the feed showed to be the only one influent factor for this process.

To prove the existence of the significance of the results in Fig. 7, was used analysis of variance of the factors and possible interactions present in that case, given in Table 7.

Table 7: Analysis of variance for the variable response Ra

Factors	Seq SS	DF	AdjMs	F	P
F	0,68445	1	0,68445	1,14456	0,298828
A	0,08000	1	0,08000	0,13378	0,718809
AF	0,46561	1	0,46561	0,77861	0,389198
B	28,80405	1	28,80405	48,16703	0,000002
BF	0,27011	1	0,27011	0,45169	0,510069
AB	1,28801	1	1,28801	2,15386	0,159469
ED	0,05120	1	0,05120	0,08562	0,773170
D	0,21125	1	0,21125	0,35326	0,559671
DF	0,33211	1	0,33211	0,55537	0,465753
C	0,61051	1	0,61051	1,02092	0,325692
DF	0,36125	1	0,36125	0,60409	0,447116
EF	1,23245	1	1,23245	2,06094	0,168267
E	1,40281	1	1,40281	2,34583	0,143005
Erro	10,76406	18	0,59800		

The analysis of variance (Table 7) was performed for all factors and possible interactions, proving that the only really significant factor for due process was the rate of progress shown by the p-value close to zero, meaning that almost 100% confidence that the mean surface roughness is affected by the feed rate.

For all of other factors, even not showing to be significant in the process, can be seen at Figure 7 that factor A (cutting speed) when is settled in the level 2 shows a variable response surface roughness better than is working in the level 1. In other words, for this process is better work in higher speeds then in the lower speeds, complying the imposed limits on levels worked.

Following the results in Table 7, was taken the two most influential factors and examined their behavior in relation to the behavior of the response variable, it was possible to build the graph in Figure 8.

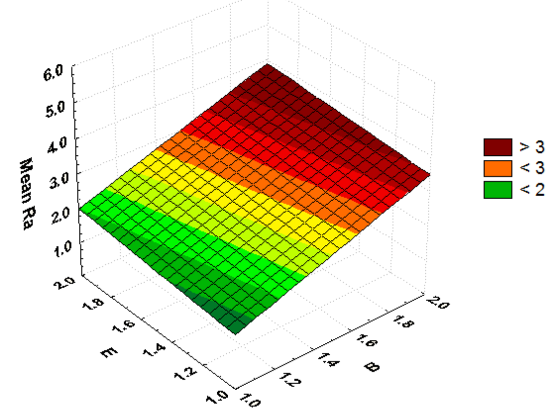

Figure 8: Behavior of the roughness in relation to feed rate x lubrification

From Figure 8, can be extract that there is a strong relationship between these two variables over the response variable roughness. Clearly, when analyzing the results, the roughness is greatly influenced mainly by increasing of the variable feed rate from level 1 to level 2. These results in a large increase in roughness values, but to analyze the behavior in relation to the lubricating fluid can observe a small increase in roughness as it does the level of Minimum quantity of fluid (MQF) to abundant, with much lower values when compared with variable advance.

This behavior is not surprising, because according withKamata and Obikawa (2007), the machining using MQF is nearly equal or often better than traditional machining fluid abundant. However, for an economic and environmental point, the minimum amount of fluid will always be a good alternative to the process, especially when the results are beneficial to the process.

To show the sensitivity of the results, contour plots for overall desirability were drawn as shown in Figure 9.

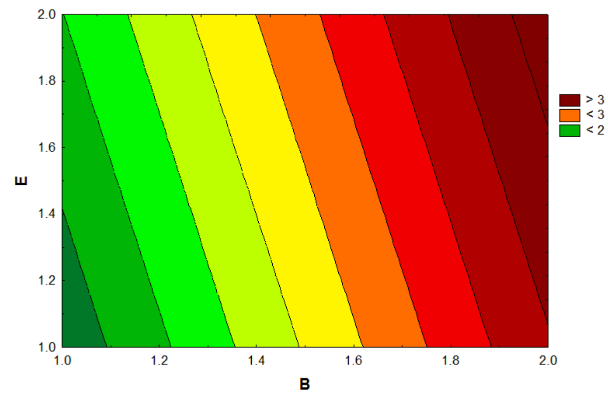

Figure 9: Behavior of the roughness in relation to feed rate x lubrification

Confirming the results from Figure 8, can be observed in the Figure 9 that the larger the feed rate, greater will be the roughness average of the machined surface, becoming evident that when working with the feed rate adjusted in 0.12 mm/revol. and MQF fluid, can be achieved results of roughness less than 2 µm, while working with the feed rate

in 0.18 mm/revol. and in an environment with abundant fluid, can be achieved roughness values greater than 3 µm.
To verify what happened with the cutting tool for both cases, where reached the highest value and lowest value for the variable response roughness, the Figure 110 was built.

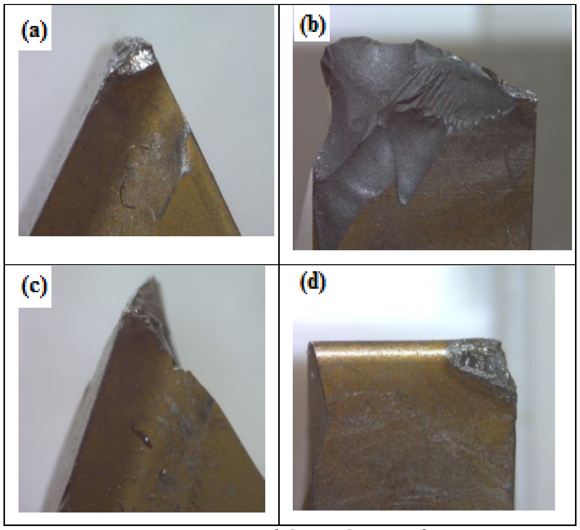

Figura 10: Representation of the tools wear for two cases in maximum and minimum roughness found. (a) and (b) represents the upside and the cutting side respectively for the run 12 and (c) and (d) represents the same but for the run 14

Comparing both cases of maximum and minimum roughness showed in the Fig. 10, is clearly see that are the same cutting tool (CP250). It is possible conclude that for the run 12 with the roughness average in about 5,15µm, was the highest value found, whereas that for the run 14 the roughness average was found in about 1,15 µm.
For the run number 12, the Fig. 10 (a) and (b) shows the condition that the tool reached after the experiment accomplished. In this case, the tool broke and didn´t support arrive until the wear of 0,5mm, in other words, this can be considered as extreme condition where was used the feed rate in the high level.
At the same way, the analysis in the Fig. 10 (c) and (d), that are the run number 14, the tool reached the wear, becoming evident that the forces generated in this case were not so great as in the run 12.
This considering has one explanation, in the run 14 was used the feed rate adjusted at the level 1 and for the run 14 at the level 2, and combining the considerations about the Fig. 8 and 9 with what was proposed with the considerations about the Fig. 10, proves that for this process in question, the use of the feed rate in high levels, cause a great effort, increasing the heat in the system tool-workpiece, leading a great deformation in the surface causing an increasing of the values of the roughness.
Taking into account all conditions and detailed explanations of each step, one can conclude that the best condition to work in the process in question is adjust the cutting speed to 90mm/revol., feed rate to 0,12mm, cutting depth 0.8mm, using the tool CP250, but how don't have any evidence of significance will be more profitable use an environment abundant using the material hot holled.

4. CONCLUSION

The use of an orthogonal array by Taguchi has helped in the choice of factors and parameters of the test application, set the sequence of experiments and the properties measured, after which the experiments were able to identify the influence of each factor and interactions for response variable roughness.
The feed rateemerged asthe only one parameterinfluent in the process. Looking to both analyses of the effectsoffactors, such asfor the analysisof variance,also observed that thesurface roughnessincreases asincreasingthe feed rate. In conclusion,to minimizethe roughness, in this process the variable feed rate must be adjusted at the level 1, in other words, use in0.12mm/revol.
The conditions that optimize the roughness in this process in question is to adjust the cutting speed to 90mm/revol., feed rate to 0,12 mm, cutting depth 0.8mm, using the tool CP250, in an environment abundant using the material hot holled.
Finally, can be concluded that the methods were successful, because the objective proposed in the study was well conducted step by step by each method, it is possible to determine the best arrangement of factors in this process.

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