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STUDY OF SURFACE FINISH AND CUTTING EFFORTS IN THE PROCESS OF TURNING THE ALUMINUM BRONZE ALLOY (UNS C63020) USING TUNGSTEN CARBIDE TOOLS WITH STANDARD AND GEOMETRY WIPER USING DESIGN OF EXPERIMENTS

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Abstract. The bronzes are a family of aluminum base alloys of copper which provides a combination of mechanical properties unmatched by any number of other alloys. Aluminium Bronze alloy shave wide application due to present high mechanical strength and corrosion resistance when compared to other bronze alloys. The turning is a machining process widely used in industry for the production of various parts and components. In order to obtain information for a better understanding of this process, it is interesting to study the machining forces and of getting its variables in response surface finish (roughness) which is extremely important for some processes our parts. Knowing these variables and the forces on the cutting tool, one can estimate not only the power required to achieve the cutting, but also have important values for building rigid machine tools capable of ensuring better performance. The machining forces may still represent an index of machinability and function as a parameter for adaptive control process .The work aims to study the machining conditions, the components of the forces and surface finish in turning Alloy Aluminum Bronze and analyze the influence of tungsten carbide tool with standard geometry and wiper (positive and negative) and the conditions cutting forces in machining.

Keywords: Bronze, Aluminum, Forces, Roughness, Machining

1.INTRODUCTION

A major goal of engineering has always been to achieve the best results with minimum cost and maximum performance. An example of this can be seen by analyzing the rapid development of aeronautic sector, which necessitated that professionals demand for tougher materials, lightweight and highly cost-effective. The competitiveness factor was present in the last twenty years, during which he was seen as a significant improvement in materials and manufacturing processes in the industry. The requirement for materials that support the propagation of fatigue cracks and stress corrosion became more evident when evaluating the lifetime of the aircraft according to Cantor et. al (2001). The great difficulty is to obtain a reliable safety factor without affecting the weight and value of the final product. Different heat treatments are employed in order to achieve this goal. Aluminum alloys constitute the majority of the structures present in a plane. The small density associated with the abundance of this metal in nature contribute to make it happen. However, materials such as aluminum bronzes are also employed on components which require higher mechanical resistance offered by the alloys commonly used. The long-term reliability and corrosion resistance operating in temperature ranges between -50 ° C and 40 ° C indicate this material for use in structures such as gears, bushings, bearings, valves and propellers, despite its high cost.

The bronzes are a family of aluminum base alloys of copper which provides a combination of mechanical properties unmatched by any number of other alloys. This feature makes this alloy is often the first choice and sometimes the only logical choice for the most demanding applications. Aluminium Bronze alloys have wide application due to its high mechanical strength and corrosion resistance when compared to other bronze alloys. The turning is a machining process widely used in industries for the production of various parts and components. In order to obtain information for a better understanding of this process, it is interesting to study the machining forces and their resulting variables in response surface finish (roughness) which is extremely important for some processes our parts.

Knowing these variables and the cutting forces on the tool, one can estimate not only the power required to achieve the cutting, but also have important values for building rigid machine tools capable of ensuring a better performance. As machining forces can also represent an index of machinability and function as a parameter for the adaptive control process (Machado et al, 1994; Ferraresi 1977).

Scientific analysis of the machining of metals, also require knowledge of the forces, and the last 90 years many dynamometers capable of measuring forces with considerable accuracy have been developed (Trent et al 1984, Roberts et al 1990). The importance of the study of the roughness increases as it increases the accuracy of fit between the parts to be coupled, where only the dimensional accuracy of shape and position is not enough to ensure the functionality of the mated pair. The surface finish is critical where there is wear, friction, corrosion and fatigue resistance appearance.

The turning significantly reduces production costs (Grzesik, 2009), preparation time (Paiva, 2007) and improves the overall quality of the product (Huang 2007). Especially considering their efficiency in reducing the processing time consumed in each operation, reduced power consumption eliminating cooling, improvement of material properties and the ability to promote low values for surface finish, removing the workpiece material in a single section instead of a long grinding operation. These benefits, however, can only be achieved with appropriate values for the process parameters as well as the correct choice of coating and tool geometry. Huang (2005) and Lima (2005) reported that the composition and properties of the tool materials are critical to the performance of machining forces, which in turn can affect the surface finish of the workpiece.

In this sense, trying to get a better understanding of the process of turning, several studies have been done recently. Some works have studied the effect of cutting conditions (vc, f, p), the influence of the hardness of workpiece and tool geometry in roughness effects of cutting fluids Montgomery (2005), tool wear and its influence on the error as the geometric influence of solid lubricants, the integrity of the surface (surface roughness and thermal damage layer) (Zhang, 2007), the effects of cooling. Most of these works establishes a relationship between the output properties of the process (surface roughness, cutting forces) and the inputs (cutting speed, feed and depth of cut).

In conventional analysis of the influence of these factors in a machining process is usually studied the influence of each one individually, which requires a large number of tests, high material consumption and machining tools, and the need to use many hours, machine, which usually makes the cost prohibitive to experimentation. In this respect, the concern to act simultaneously on the quality and cost of each process requires companies to use techniques nontrivial planning and quality improvement. To achieve these objectives, many processes have used the experimental modeling. Mathematical models can be constructed from observation and experimentation planned. This strategy is known as observational methodology of Design of Experiments (DOE), which consists of design experiments capable of generating appropriate data for effective statistical analysis, resulting in valid and objective conclusions (Montgomery, 2004) . All these works aim to optimize response variables in machining processes, obtained from a small but effective amount of experiments.

With the innovation of the tool geometries wiper, it became possible to achieve a high quality finish in turning operations when compared with conventional tools. For some cases, the finish can also advances to keep two to four times greater than the common, leading to increased productivity. When the information of the experiments are analyzed statistically, it is guaranteed that the product will be designed with robustness to variations of the manufacturing process itself, the environment and user. Further, statistical analysis is important because a slight difference between the specifications of a product or adjusting the levels of the control factors of a manufacturing process can mean the gain or loss of production time and quality of machining tools product, which translates into large economic gains or losses for the company.

The present work aims to study the machining force components in turning aluminum bronze alloy (UNS C63020).

1.1. THEORETICAL DEVELOPMENT

Developed between 1920 and 1930 by Fisher, and subsequently enhanced by leading researchers in the field of statistics as Box, Hunter (1978) and Taguchi (1986). The Design of Experiments (DOE) is a relatively old. After World War II, the DOE was introduced in the chemical industry and in industrial companies in the United States and Europe. The growing interest in the DOE also occurred in Brazil and the rest of the world. Currently companies greatly increase your productivity with the use of this tool.

Planning and Analysis of Experiments (DOE) methodology is employed to evaluate the magnitude of various sources of variation that influence the process (Montgomery, 2001). Should start with the identification and selection of the factors that may contribute to the variation, it is desirable, then the selection of a model that includes the factors chosen experiments and plan efficient to estimate their effects. Once the experiments, we proceed to the analysis to estimate the effects of the factors included in the model using appropriate statistical methods, culminating in inference, interpretation and discussion of the results, recommending improvements when necessary.

During the conduct of experimental rounds, all factors can be changed simultaneously. Thus, there are several ways to combine them, called arrays. The full factorial design is the arrangement for which the number of experiments is equal to the number of experimental levels, the high number of factors. The full factorial arrangement can be generated for any number of factors and levels change each experiment. However, a large number of factors can render impossible an experimental procedure. In this case and there is little interest in the interactions, one can neglect them, using half fraction of the complete experiment (2^{k-1} experiments).

According to Montgomery (2004), the methodology of Design of Experiments (DOE) is the use of statistical techniques capable of generating appropriate data for a statistical analysis resulting in valid and objective conclusions. Consists in performing experiments in which factors of a process under analysis are varied simultaneously in order to measure their effect on the variable (or variables) output of such a process. Correspond to a full factorial DOE technique in which all the possible combinations of levels of experimental factors are exercised so as to cover the entire experimental space. The number of runs is equal to the number of levels to the high number of factors. For factorial experiments on two levels, the total number of runs required to N evaluate the effect factor k is given by N = 2k. DOE methodology, the test used to evaluate the significance of the effects of changes in the levels of the factors or the effects of interactions between levels on the output of the process is a hypothesis test for means. In the full factorial technique, the test used is the analysis of variance, or ANOVA (Montgomery, 2004). In this work, the methodology has been used as a design tool for obtaining the modeling of roughness. Although there is no single theoretical model that enables the prediction of roughness, the literature points towards the cutting parameters are determinant in predicting (Shaw, 2004). Cus et.al. (2006) suggested empirical models for linear and exponential workpiece roughness as a function of cutting speed (vc), feet (f) and depth of cut (ap).

The first-order polynomial function developed for a Project Methodology of experiment that relates a given response y with k input variables has the following form described by Equation (1) (Montgomery, 2005):

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \ldots + \beta_k x_k + \varepsilon \tag{1}$$

Where: y is the response of interest, input parameters xi, β0, βi, βii, βij are coefficients to be estimated k = p number of input parameters and is considered as the error. However, if there is curvature in the system, then the approximation function most used is a polynomial of higher order, as the second-order model presented by Equation(2):

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i<j}\sum \beta_{ij} x_i x_j + \varepsilon \tag{2}$$

1. EXPERIMENTAL PROCEDURE

1.1 Machines, tools, materials and Measuring Instruments

For the turning process developed in this work we used a CNC Turning Center Galaxy 240, with axis maximum power of 20 HP; maximum speed of 6.000 rpm; tower with twelve positions and maximum torque of 110 Kgf.m.

The experiments performed in this work were performed at the Laboratory of Automation Manufacturing (LAM), Federal University of Itajubá (UNIFEI). In the experiments we obtained a data set that allowed to analyze the effects of cutting parameters and machining forces on the roughness in turning of Bronze Aluminum alloy.

In this study was used to measure cutting forces a dynamometer KISTLER type 9443B, a microcomputer equipped with a data acquisition board and program for reading and converting data (pC) to (N) (Fig. 1). As for the workpiece materials and tools are presented below.

Table 1:Chemical composition of the aluminum bronze alloy

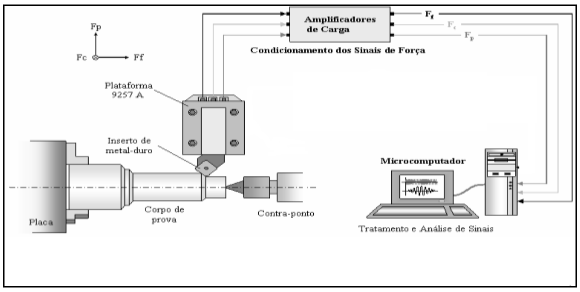
Cu	Al	Ni	Fe
78,5%	10,5%	5,1%	4,8%

Tools:

- Class ISO S15 carbide coated (TiAlN) - DNMG 150408 - SM - GC1105
- Class ISO S25 carbide coated (TiAlN) - DNMX 150408 - WF - GC1125

The software used for data acquisition was set to 150 readings for each test. Each test was repeated three times and was taken as a result the arithmetic mean of the three values. In Figure 1 is shown the mounting system used for the tests.

Figure 1. Mounting system for measuring forces, along the lathe.



For the tests which were considered variations feed were used the same cutting parameters in three different conditions: test with tools coated with TiAlN and to dry, test with tools coated with TiAlN with cutting fluid and test tools uncoated and to dry. The objective was to compare the effect of fluid on cutting force and also tools coated and uncoated in turning to dry (Fig. 2).

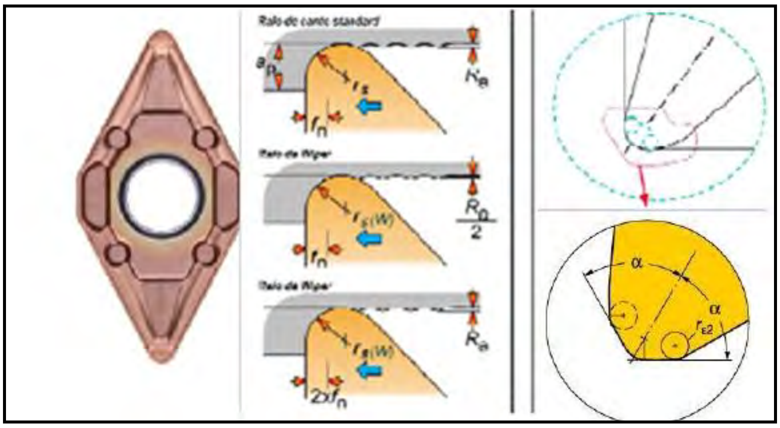


Figure 2: shows a comparison of the influence of the rays straighteners tip geometry of the tool and its combined effect with the feet in the roughness of the workpiece relative to the standard radius (Sandvik,2010).

The workpiece used in the machining process is made with dimensions of Ø 25 mm x 100 mm for normal negative tool and for negative tool with wiper geometry. All specimens were heat treated according to standard AMS 4590 (TQ50), they were previously tempered at a temperature range of 843-899°C, the material was kept in this condition for at least 2 hours and then was taken to water to perform quenching and made tempering raising the temperature to the range 482 to 538°C for at least 2 hours the cooling after the annealing was done in air until reaching ambient temperature. In this treatment the alloy reaches the point where there is the formation of β phase, when quenched, allows the formation of a martensitic microstructure β', by tempering the alloy, the martensitic transformation voltages are derived from the attenuated. After this heat treatment, the hardness was between 31 and 34 HRC (table 1).

1.2 Methodology of the tests

Data collection itself is a very important activity in the execution of the work. A poorly designed database can lead to unsatisfactory results or disabled. Thus, it is extremely important to the detailed planning of the experiment and its proper execution and registration.

For this model a new condition was added: the behavior of optimization ahead to the possible presence of noise factors, showing that it is possible to provide appropriate treatment and still get consistent machining parameters. Figure 3 shows the process diagram for the system investigated. The control variables for this procedure were adopted cutting speed (vc), feet (f) and tool geometry negative (normal and wiper). These variables are known to be the most important, since it strongly influences the turning process, especially the surface finish of the workpiece and the machining forces.

Figure 3 - Process Turning Bronze Aluminum Source: Paiva, 2010 (adapted by the author).

Table (2) presents the three factors: cutting speed, feed, tool geometry (normal and wiper) and their respective levels of variation. Levels were specified in terms of data recommended by manufacturer's catalog of tools (Sandvik, 2010) and was also produced a factorial design (three parameters and two levels) for the tests.

Table 2. Machining parameters used.

Process parameters	Symbol	Unit	Levels of Factors			
				-1	+1	
Cutting Speed	vc	m/min		200	300	
Feed	f	mm/v		0,15	0,30	
Geometry	ap	mm		normal	wiper	

Turning tests were sized to provide an accurate way to study the influence of the cutting speed, feed, and tool geometry surface roughness (Ra, Rt) and machining forces (Fx, Fy and Fz) of the workpiece by applying the methodology of design of experiments (DOE).

Each specimen machined, it was removed from the machine for measuring roughness. The roughness measurements were performed four times in the points (A, B, and C), according to the scheme illustrated in Figure (4), after the roughness measurements were performed the arithmetical average roughness values.

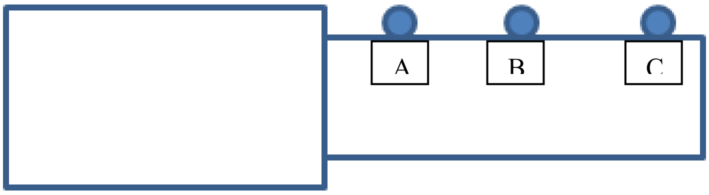


Figure 4. Reading positions roughness in the specimens.

4. Results and discussion

Through the development of a complete factorial arrangement with one (1) Replica and without center points will proceed to the analysis of data obtained experimentally. Table 3 shows the results of Ra and Rt roughness meter in microns (um) and the cutting forces Fx, Fy and Fz (N) for sixteen assayed conditions necessary to obtain the respective response followed for replicas the tools negative.

It is noted that the roughness parameter Ra obtained in tests for aluminum bronze alloy were relatively low, since the feed (f) ranged from 0.15 to 0.30 mm /v. The average roughness Ra was in the range from 0.26 to 3.63 µm and the maximum roughness Rt was in the range of 2.7 to 22.35 µm. Justified these results by Ra wiper effect of the geometry of the cutting tool carbide coated and low hardness part in the range of 35 HRC. It should be noted that the CNC lathe used is small and presents no great rigidity.

Table 3 - Factor 2^3 complete with replicas tool for negative response to roughness (Ra and Rt) and machining forces (Fx, Fy and Fz)

Nº Test	**vc (m/min)**	**f (mm/v)**	**Geometry (normal-wiper)**	**Ra (µm)**	**Rt (µm)**	**Fx (N)**	**Fy (N)**	**Fz (N)**
1	300	0,30	wiper	1,19	7,11	148,02	119,63	647,55
2	300	0,15	wiper	0,29	2,70	186,34	138,82	329,81
3	200	0,30	wiper	1,59	8,15	134,70	123,03	528,23
4	300	0,30	wiper	1,20	5,62	160,52	125,04	694,02
5	200	0,30	Normal	3,71	18,92	94,34	116,82	521,47
6	200	0,30	Normal	3,74	19,21	87,27	113,02	512,18
7	300	0,15	Normal	0,86	4,61	115,59	137,44	282,29
8	200	0,15	wiper	0,29	2,75	200,12	141,97	364,02

9	300	0,30	Normal	3,68	16,29	80,18	104,68	505,49
10	200	0,15	wiper	0,29	2,75	198,55	142,74	352,51
11	300	0,15	wiper	0,26	2,57	186,58	139,74	322,30
12	200	0,30	wiper	1,61	7,82	143,77	125,72	607,16
13	300	0,30	Normal	3,63	15,78	87,74	107,18	505,88
14	300	0,15	Normal	0,87	4,61	110,51	135,82	269,72
15	200	0,15	Normal	0,74	3,69	117,00	136,57	298,02
16	200	0,15	Normal	0,74	3,69	114,20	132,70	300,00

The analyzes show that the experiments were consistent, especially with respect to repeatability, since the roughness Ra and the forces Fx, Fy and Fz in the turning of aluminum bronze alloy, showed very similar values in the tests and their respective replicas, a fact which shows the consistency of the tests, which will be of great importance to the smooth running of this study. Helded the analysis of variance (ANOVA) - which consists of a test to compare the averages, the full factorial design for the three factors and two levels (2^3), with its replica for the response Ra and Rt roughness and cutting forces (Fx, Fy and Fz).

Figure (5) shows a comparison of the main effects of cutting conditions, speed, feed and tool geometry on surface roughness Ra and Rt and machining forces Fx, Fy and Fz. Observe that all elements influence the roughness Ra, highlighting the elements, feed and the combination of feed with geometry. Firstly, there is the machining feed rate factor as being the element which, by a variation in their level causes a higher influence on the surface roughness Ra, followed by the geometry and cutting speed, and the interactions between cutting speed and feed machining and between feed and geometry. As can be seen in fig. 5, the three-way interaction, as well as the interaction between cutting speed and feed and cutting speed and geometry also showed roughness Ra influences.

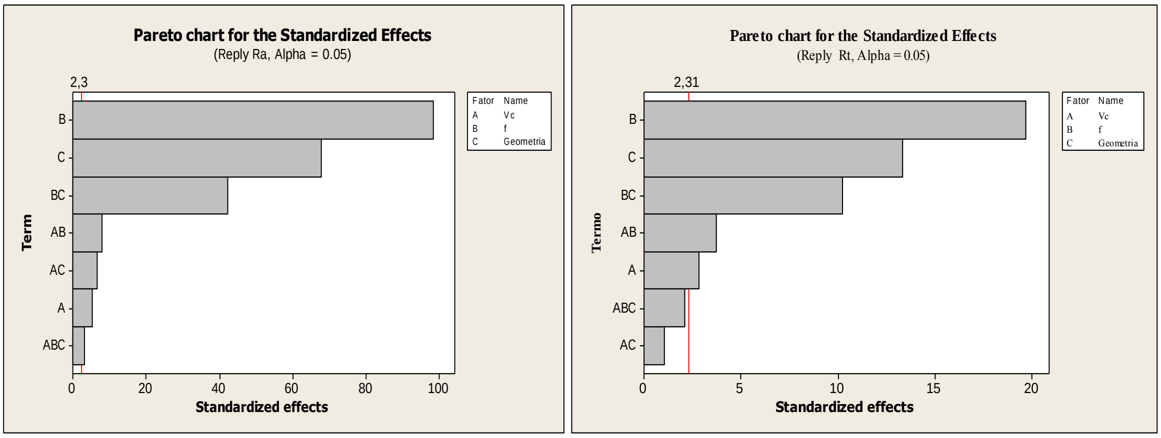


Figure 5 - Pareto Chart of standardized effects for roughness Ra and Rt

Making a more accurate analysis for feed force (Fx) finds that the most significant factor was the geometry followed by feed (f), note also that the cutting speed (vc) and the interaction with the geometry was not a factor that influenced the feed force (Fx), but the interaction between cutting speed (vc) and feed (f) and the triple interaction between cutting speed (vc), feed (f) and geometry one can already notice a small influence as shown fig. 6.Already for passive force (Fy) can be seen that the most significant factor that influenced the feed (f) was followed by geometry, since the cutting speed (vc) had also influences contrary to what was seen in the analysis prior to the cutting force (vc), note also that the interaction between feed rate (f) and geometry also had an influence on the percentage, followed by the triple interaction between cutting speed (vc), feed (f) and geometry, as is shown in figure 7.Already cutting force (Fz) note that the most significant factor was the feed (f) and followed by the geometry, since the cutting speed (vc) and the interaction between speed cutting (vc) and the geometry and feed rate (f) and the geometry did not have significant influence, since the three-way interaction between cutting speed, feed rate (f) and the geometry had an influence on the cutting force (Fz), as can be noted in figure 8.

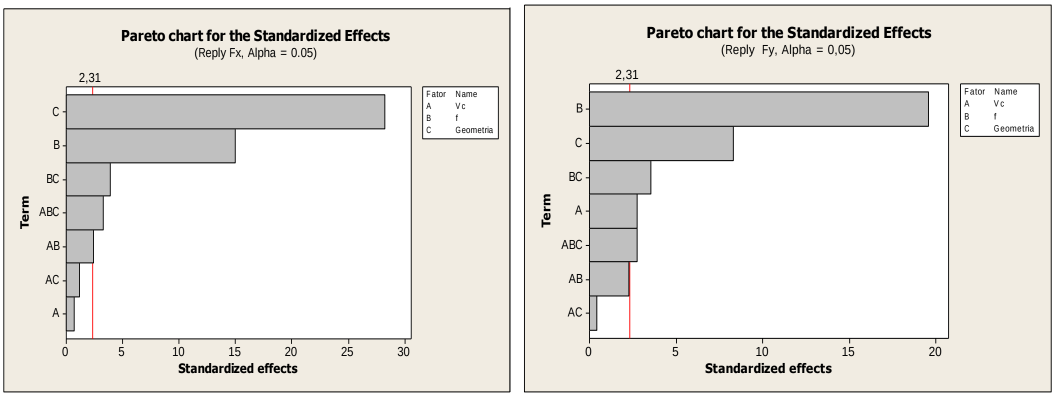


Figure 6 and 7 - Pareto Chart of standardized effects for Cutting Force (Fx and Fy)

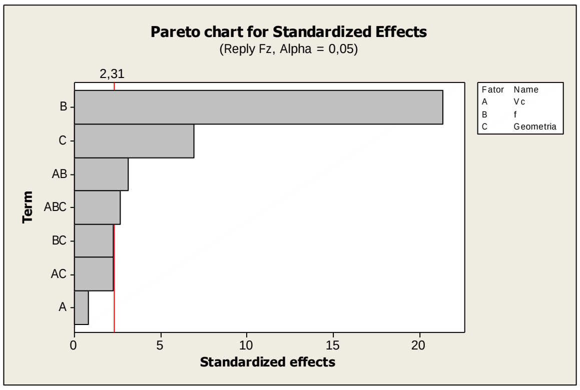


Figure 8 - Pareto Chart of standardized effects for Cutting Force (Fz)

Figure 9 and 10 graph shows provide the main effect of vc, f geometry surface roughness Ra and Rt to normal geometry and wiper. Note that the effect feed (f) contributed to the increase of Ra and Rt roughness when its top level, that is, with the increase in the advancing and Rt roughness Ra also increases, contrary to what happens with the geometry of tool, which was already expected, since with wiper geometry expected to find low roughness due to the geometry of the tool edge, if comparing with the tool geometry normal. Note that the cutting speed (vc) does not obtained a strong influence on the roughness Ra compared with the factor feed (f).

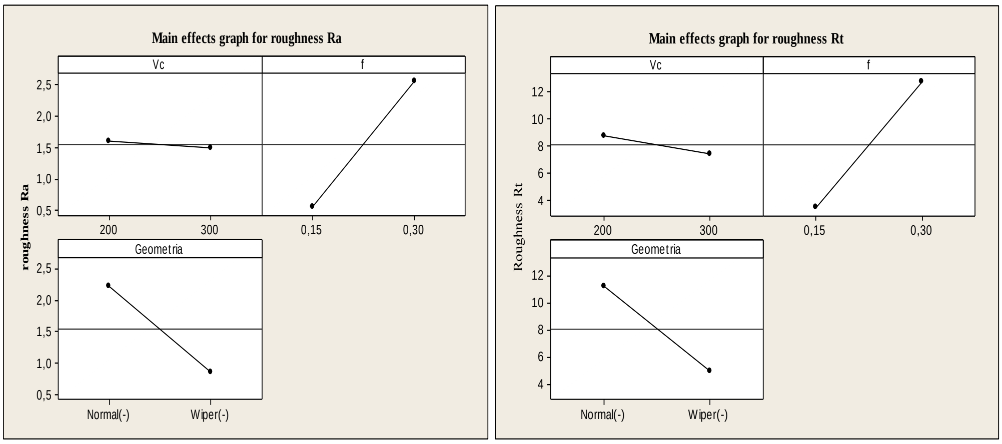


Figure 9 and 10 - Charts of the main effects of vc, f and geometry in roughness Rt

Figure 11 shows the plot of the main effects vc, f geometry in feed force Fx with the normal geometry, and wiper. Note that the effect feed (f) contributed to the reduction in feed force when its top level, that is, with increasing feed force also decreases, contrary to what happens with the geometry of the tool, what it was to be expected, because as Diniz (2008) with an increase in Kr generates an increase in feed force, so Kr tool wiper geometry is 93° and the normal geometry Kr is 62.5 º justifying this increase in feed force Fx. Nota also that the cutting speed (vc) did not have an influence on the feed force is compared with the advancement and geometry.

Note in Figure 12, the Main effects graph to vc, f and geometry in passive force Fy with the geometry normal and wiper. Note that the effect feed(f) competed for a reduction of the passive force when its top level, that is, with increasing feed passive force also decreases, and contrary to what happens with the geometry tool more lightly. Note also that the cutting speed (vc) obtained a small influence on the feed force is compared with the factor feed and geometry.

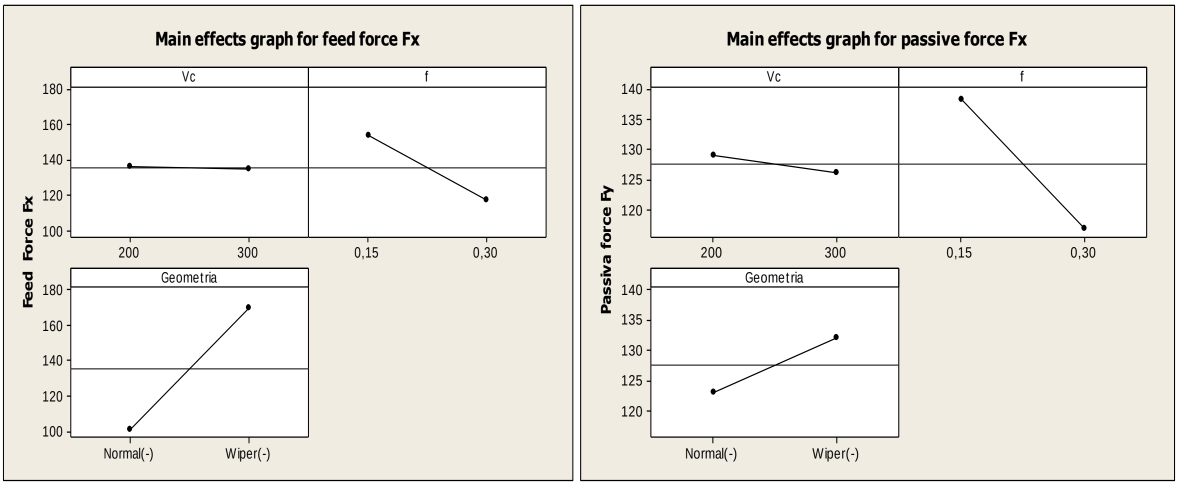


Figure 11 and 12 - Graphs of the main effects of vc, f and geometry in roughness for Advancement and passive forces (Fx and Fy)

Note in Figure 13, the main effects graph to the vc, f and geometry in cutting force Fz with the normal geometry and wiper. Note that the effect feed (f) competed for one increase in cutting force when its upper level, in other words, with increased feed the cutting force also increases, therefore the increased feed contact area between tool and workpiece increases, so that there is friction and the cutting force increases.

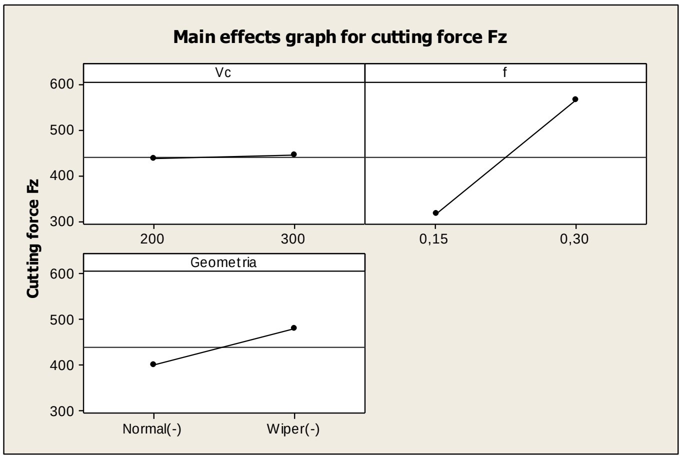


Figure 13 - Graphs of the main effects of vc, f and geometry in roughness for cutting force (Fz)

Table (4) presents the analysis of variance (ANOVA) for the average roughness Ra, which shows that the P values are less than 5% (significance level) to advance to the cutting speed, geometry and triple interaction. Depending on the ANOVA can be seen that the three cutting conditions significantly influenced the roughness Ra, its main effects. It can be seen that the linear model provides an excellent fit obtained for Ra (R^2 adj = 99.91%) not considering the implementation of all terms in the model. The coefficient of determination measures how the model explains the variation of the data and the closer to 100%, the better the model considered. Table (4) presents the analysis of variance (ANOVA) for overall roughness Rt, which shows that P values are less than 5% (level of significance) for the three factors, cutting speed, feed and geometry and for double interactions between cutting speed and feed and feed and interaction geometry. As for the interaction between cutting speed double and triple interaction between geometry and cutting speed, and geometry and feed note that the P value was greater than 5%, we can rule out the interaction between their dual variables. A Equation (3 and 4) show the obtained linear mathematical model, and the coefficients take into account the coded variables. This demonstrates that the chosen experimental levels lead to an answer close to optimum region for the surface roughness Ra. Analogously was carried analysis of variance (ANOVA) for the maximum roughness Rt, which was obtained with a linear fit (R^2 adj = 97.87%), not considering the implementation of all terms in the model.

Table 4. ANOVA for the response average roughness (Ra) and total roughness (Rt)

TERM	**COEF (Ra)**	**P (Ra)**	**COEF (Rt)**	**P (Rt)**
Constant	1,5513	0,000	8,088	0,000
vc	-0,0538	0,001	-0,677	0,021
f	1,0087	0,000	4,667	0,000
geometry	-0,6950	0,000	-3,154	0,000
vc x f	-0,0813	0,000	-0,878	0,006
vc x geometry	-0,0675	0,000	0,243	0,335
f x geometry	-0,4350	0,000	-2,426	0,000
vc x f x geometry	-0,0325	0,013	0,502	0,067
S=0,0410792 (Ra) **S=0,947724 (Rt)**	R-Sq(pred)= 99,80%	R-Sq(adj)= 99,91%	R-Sq(pred)= 95,46%	R-Sq(adj)= 97,87%

The models, however, have a very good fit around 100% (R-Sq (adj) = 99.91% and 97.87%) with a small error term S (0.0410792) than the present lack of fit. For this reason it was decided to employ this work a linear mathematical model, which can be written in coded form, as shown by the equation 3 and 4 below:

$$Ra = 1,5513 - vc*0,0538 + f*1,0087 - geometry*1,3900 - vc*f*0,1625 - vc*geometry*0,1350 - f*geometry*0,8700 - vc*f*geometry*0,0650 \qquad (Eq.3)$$

$$Rt = 8,088 - vc*0,677 + f*4,677 - geometry*3,154 - vc*f*0,878 + vc*geometry*0,243 - f*geometry*2,426 + vc*f*geometry*0,502 \qquad (Eq.4)$$

Table (5) presents the analysis of variance (ANOVA) for the feed force (Fx), which shows that the P values are less than 5% (significance level) for feed and geometry, since the interaction dual between cutting speed and geometry is observed that the value of P is greater than 5%. Depending on the ANOVA can be seen that the three conditions cutting force Fx significantly influenced by their main effects. It can be seen that the linear model has achieved an excellent fit for Fx (R^2adj = 98.59%) not considering the implementation of all terms in the model. The coefficient of determination measures how the model explains the variation of the data and the closer to 100%, the better the model considered.

In the same table (5) presents the analysis of variance (ANOVA) for the passive force (Fy), which shows that P values are less than 5% (significance level) for the three factors, cutting speed, feed and geometry and the double interactions between cutting speed and feed and feed and interaction geometry. As for the double interaction between cutting speed and geometry, cutting speed and feed it is noted that the value of P was greater than 5%, we can discard the dual interaction between the respective variables. It is also evident that the linear model has achieved an excellent fit for Fy (R^2adj = 96.95%) did not also considering the implementation of all terms.

The same was shown in table (5) also presents the analysis of variance (ANOVA) for the cutting force (Fz), which shows that the value of P for the cutting speed and the double interactions between geometry and cutting speed and feed and geometry. As for the other variables observed that the value of P is less than 5%. One can also observe that the value of (R^2 adj = 97.21%) presents an excellent fit for Fz and also does not consider the implementation of all terms.

Table 5 - ANOVA of the full factorial design with 2^3 replicates for Cutting Force (Fz), feed force (Fx) and Passive force (Fy).

	Fz		**Fx**		**Fy**	
TERM	**COEF**	**P**	**COEF**	**P**	**COEF**	**P**
Constant	440,041	0,000	135,34	0,000	127,56	0,000
vc	4,592	0,457	-0,90	0,480	-1,51	0,024
f	125,207	0,000	-18,27	0,000	-10,67	0,000
geometry	40,659	0,000	34,49	0,000	4,53	0,000
vc x f	18,396	0,014	2,95	0,042	-1,24	0,052
vc x geometry	13,128	0,056	1,44	0,271	0,23	0,678
f x geometry	13,333	0,053	-4,80	0,004	1,94	0,008
vc x f x geometry	15,429	0,030	4,03	0,011	1,50	0,025
	R-Sq(adj)= 97,21%		**R-Sq(adj)= 98,59%**		**R-Sq(adj)= 96,95%**	

Equation (5, 6 and 7) show the obtained linear mathematical model, and the coefficients take into account the coded variables. This demonstrates that the chosen experimental levels lead to an answer close to optimum region for machining forces Fx, Fy and Fz. The models, however, have a very good fit around 100% R-sq (adj) to the error terms greater that the errors S roughness of Ra and Rt, which does not present a lack of fit. Therefore decided be employed in this work the linear mathematical model, which can be written in a coded form, as shown by equation 5, 6 and 7 below:

$$Fx = 135{,}34 - 0{,}90*vc - 18{,}27*f + 34{,}49*geometry + 2{,}95*vc*f + 1{,}44*vc*geometry - 4{,}80*f*geometry + 4{,}03*vc*f*geometry \quad \text{(Eq.5)}$$

$$Fy = 127{,}56 - 1{,}51*vc - 10{,}67*f + 4{,}53*geometry - 1{,}24*vc*f + 0{,}23*vc*geometry + 1{,}94*f*geometry + 1{,}50*vc*f*geometry \quad \text{(Eq.6)}$$

$$Fz = 440{,}041 + vc*4{,}592 + 125{,}207*f + 40{,}659*geometry + 18{,}396*vc*f + 13{,}128*vc*geometry + 13{,}333*f*geometry + 15{,}429*vc*f*geometry \quad \text{(Eq.7)}$$

Many of the factors that influence the values of cutting force (Fz) also influence the feed forces (Fx) and passive force (Fy), but others, such as the radius of the tool edge and position angle (Kr) and inclination angle (λs) have strongest influence on these two components of the machining force.

Figures 14a, 14b and 15 show these influences. It may be noted that these figures, as the position angle (Kr) and inclination angle (λs) grow feed forces and passive forces for both normal geometry as well for wiper geometry is also grow. Note the growth of the position angle (Kr) generates a feed force increase, especially when (Kr) is increased. The influence of the inclination angle (λs) and position angle (Kr) is directly proportional to the growth of same. Observed also that, in all tests, either with normal tool or wiper geometry, an increase in the values of feed consequently resulted in an increase in cutting forces. In fact, such behavior was expected, since an increase in feed provides direct increase of the contact area between the chip and the tool thus causing friction between them generate greater force.

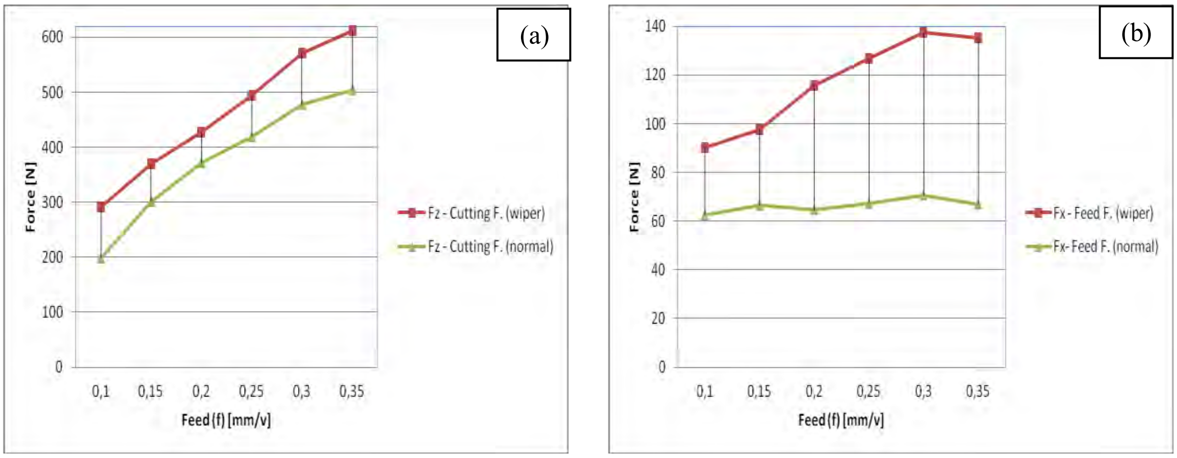


Figure 14a , 14b - Variation of forces Fz, Fx with feed for normal and wiper tool geometry (Negative)

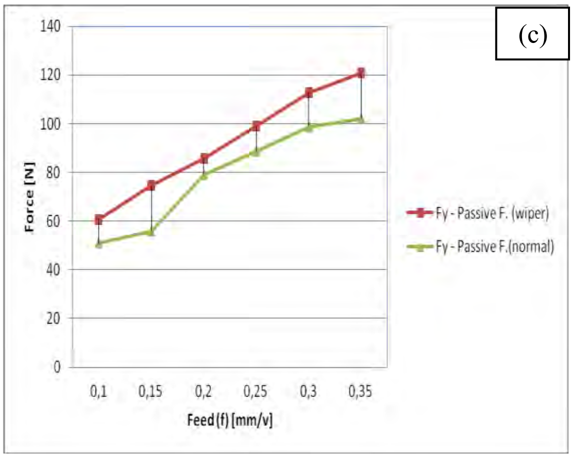


Figure 15 - Variation of forces passive Fy with feed for normal and wiper tool geometry (Negative)

In the coming figures 16a and 16b, we note a large influence of feed (f) in the cutting force (Fz), since the other components can also notice an influence on the feed forces (Fx) and passive force (Fy) for both normal and for wiper geometry of the tool negative.

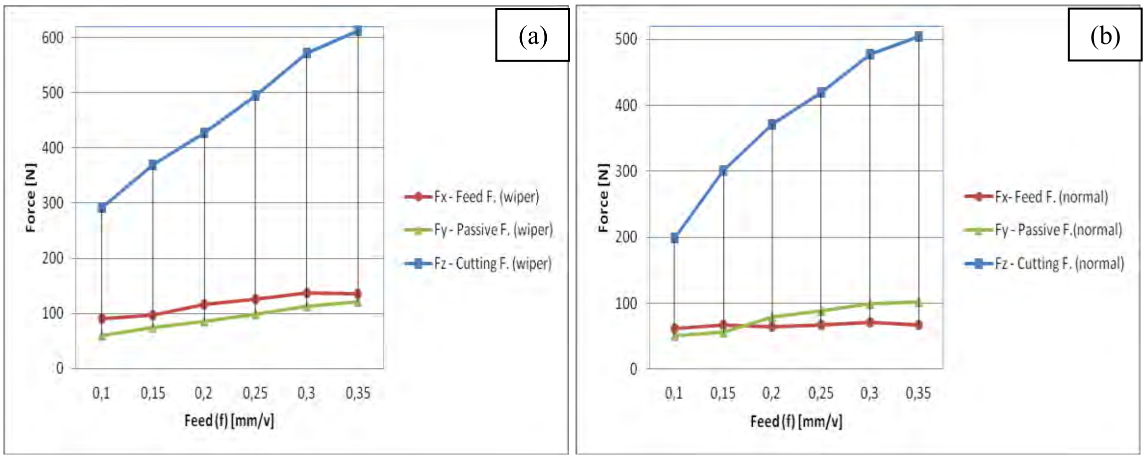


Figure 16a and 16b. Change Forces (Fx, Fy and Fz) with feed for normal and wiper tool geometry.

5. CONCLUSIONS

- Factors cutting speed (vc), feed rate (f) and the geometry exert significant influence on the surface roughness Ra and Rt, and the increase of each contributes to the increase of surface roughness Ra, mainly feed rate (f);
- In keeping with that indicated in the literature, increasing the cutting speed produces a general reduction in machining force however this effect is very small. The tool geometry and feed, caused an increase in the machining force larger than the other machining parameters during a turning operation.
- Models of surface finish obtained through the methodology of design experiments (DOE) forecasts performed very close to reality, with a margin of error of less than 5% for both cases, it shows the feasibility of modeling of machining processes this technique (DOE);

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7.RESPONSIBILITY NOTICE

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