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The use of cutting fluids aims to meet the needs of cooling and lubrication during the material removal process. Therefore, the present work sought to investigate the results regarding the quality of the surface finish of AISI 316 steel, using a complete factorial planning (DOE - Design of Experiments) of 03 factors in 2 levels (23), considering input speed, feed and depth of cut and 01 qualitative factor, which are vegetable cutting fluids (commercial - quimatic, cotton and canola) and also in the dry condition, using for pliation the technique of the Minimum Amount of Fluids (MQF) with a flow of 90 ml/h, totaling 32 tests, analyzed for their effects of mean roughness (Ra). The results showed that vegetable oils presented roughness close to commercial oil, which demonstrates a potentiality as alternatives for replacing commercial cutting fluids.

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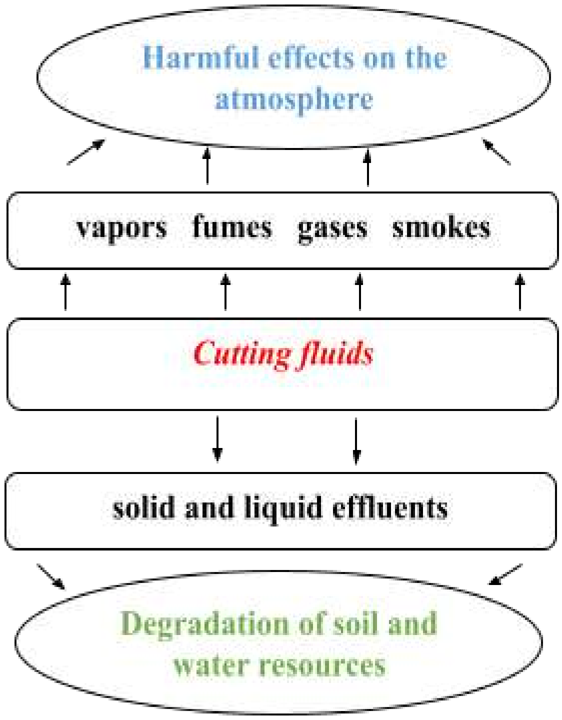
I. INTRODUCTION

In recent years there has been a greater concern regarding the continuous improvement of methods, processes and technical aspects of manufactured products. In its entirety, mechanical manufacturing processes currently seek the best adaptation between machine and tool to obtain a better quality and productivity. In this way, machining manufacturing processes are essential in the mechanical metal industry, as most products undergo some machining operation in some of their production stages. The DIN 8560 standard[1] defines that machining is the manufacturing process that gives the part shape, dimensions, finish or even a combination of any of these three, through the removal of material in the form of chip material part of the part removed by the cutting tool, characterized by an irregular shape.

By analyzing the environmental aspects of machining operations, it is possible to identify several sources that are aggressors to the environment, including cutting fluids or lubri-refrigerant fluids, which are used in large quantities to increase the life of the tools and improve the quality of the parts produced[2]. Conventional cutting fluids that are used to ease the wear of cutting tools and increase their service life pollute the environment and produce diseases to professionals in contact with these fluids. Therefore, the use of vegetable oils appears as a good option in place of petroleum products, since they are less harmful to the environment, biodegradable, renewable and less toxic[3]. Figure 1 shows the environmental aspects related to the use of cutting fluids in machining processes.



Source: Adapted from ARAÚJO JÚNIOR [2]

Figure 1: Finish rating of machined surface

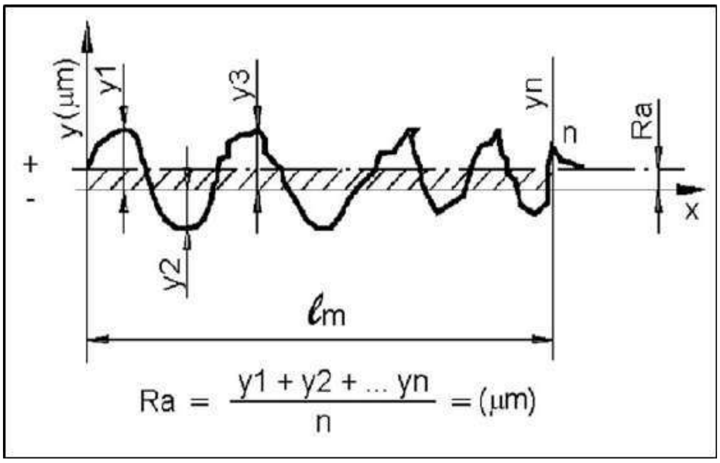
In this way, there is a high trend towards environmental concerns caused by the use of cutting fluids in machining processes and strong emphasis today is given to environmentally correct technologies, such as dry machining[2].

On the other hand, despite persistent attempts to completely eliminate the use of cutting fluids, in many cases cooling is still indispensable to achieve economically viable tool lives and required surface qualities, such as machining difficult to machine materials and manufacturing components that require high dimensional accuracy[4].

According to SHAW[5], the quality of a machined surface is one of the most important points to be considered during the machining process.

Surface quality is the term that involves several factors, such as: surface finish and absence of cracks, chemical alteration, thermal damage and residual tenare, besides being the characteristic through which the requirements or metallurgical changes that have developed due to machining such as: Phase transformation, encruamento, grain size, recrystallization, inclusions in the material, among others. To optimize cutting conditions and thus obtain better quality on the surface of the material, cutting speed and feed are the two most important parameters that can be adjusted by the operator. The depth of cut is usually relative to the initial and final diameter of the bar, which should be considered, as the removal rate of the material directly influences the finishing[6].

The most used parameters to quantify roughness in the conventional machining processes are average roughness (R_a), total roughness (R_t) and maximum roughness (R_y). The average roughness is applied in most manufacturing processes, it is also known as Ra (roughness average) or CLA (center line average) which means center of the midline[7]. The mean roughness (R_a) is defined as the arithmetic mean of the absolute values of the variables of the distance orders nothings (y), of the points of the roughness profile in relation to the midline within the measurement path (lm). Figure 2 shows this magnitude at the length of a measurement path[8].



Source: Adapted from NOGUEIRA [7]

Figure 2: Average roughness (Ra)

Given the scenario exposed, the objective of this research was to analyze the fluid effects of plant based cutting, considered environmentally correct, in the process of external cylindrical turning of AISI 316 steel, with application through the MQF method (Minimum Amount of Fluid), to determine through statistical analysis (DOE - Design of Experiments, 2^3) the best technical performance conditions of the machined components through the evaluation of the roughness of the machined surfaces.

II. MATERIALS AND METHODS

2.1 Experimental planning

The experimental planning was elaborated based on a complete factorial planning (2^k) of 03 factors (2^3), establishing relationships with some quantities that involve the machining process, considered as the input variables: cutting speed (v_c), feed (f) and depth of cut (a_p), with variation at two levels each and 01 qualitative factor of comparison: lubri-refrigerants condition, which are:

- Refined vegetable oils of Cotton and Canola;
- Commercial quimatic oil, which is a commercial cutting fluid also ecological and biodegradable, which contains characte-ristics necessary for application in machining of ferrous metals through the MQF technique;
- Dry condition, i.e. without using any type of lubrirefrigerant.

All oils were applied using the MQF technique, with a flow rate of 90ml/h, performing 8 combined tests for each qualitative condition, totaling 32 trials. The data adopted in the experiment are described in Table 1.

Table 1: Planning matrix for specific roughness measurement machining tests

Variables				
Input				Output
Quantitative			Qualitative	Quantitative
v_c (m/min)	f (mm/rot)	a_p (mm)	Fluids	Roughness Average
75.8	0.173	1.5	Dry; Cotton vegetable fluid; Canola plant fluid; Quimatic commercial fluid	R_a
119.3	0.491	2.0		

2.2 Material specification and cutting tool

The machine tool used in the machinability tests was the universal lathe of the brand NARDINI, model ND 195S, with installed power of 6.12 HP and maximum rotation of 1600 RPM. To perform the machining tests was an AISI 316 steel bar with circular section of 38mm in diameter, which was dismembered into 04 specimens of 200mm in length each, where each specimen was destined to a test condition (dry, with commercial oil, with canola vegetable oil, with cotton vegetable oil). The illustration of the specimens is shown in Figure 4.

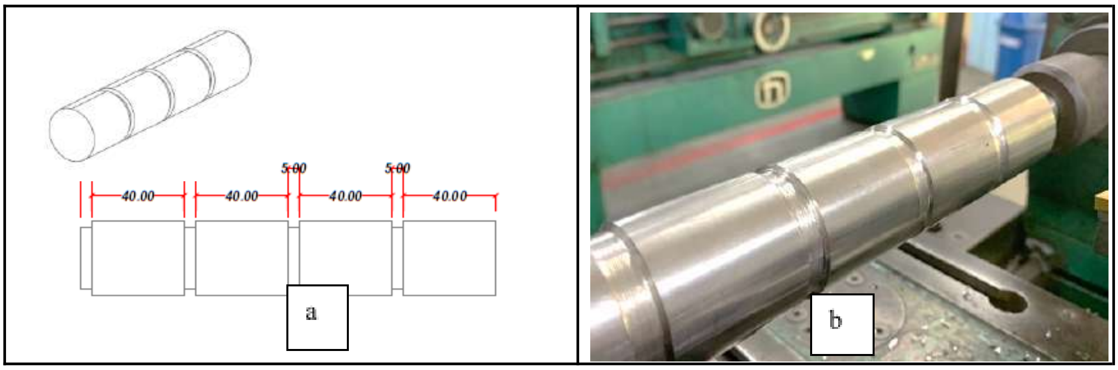


Figure 2: (a) Design of the test body (b) Machined test body

The selection of the material is due to a favorable combination of properties, such as: corrosion and oxidation resistance, hot mechanical resistance, cold workability and weldability.[9] The elements that are part of the chemical composition of austenitic stainless steel AISI 316 are presented in Table 2.

Table 2: Chemical composition steel AISI 316 (in % mass)

Elements	C Carbon	Si Silicon	Mn Manganese	P Phosphorus	S Sulfur	Cr Chromium	Mo Molybdenum	Ni Nickel	Al Aluminum	Co Cobalt
Average concentration obtained (%)	0.039	0.46	1.77	0.044	0.024	16.95	2.49	10.9	0.01	0.20
Specification	0.08 Máximo	1.00 Máximo	2.00 Máximo	0.045 Máximo	0.030 Máximo	16.00 - 18.00 Máximo	2.00 - 3.00 Máximo	10,0 - 14,0 Máximo	-	-
Elements	Cu Cuprum	Nb Niobium	Ti Titanium	V Vanadium	W Tungsten	Pb Lead	Sn Tin	B Boron	N Nitrogen	Fe Iron
Average concentration obtained (%)	0.039	0.46	1.77	0.044	0.024	16.95	2.49	10.9	0.01	0.20

Source: Labteste[9]

The insert used to perform the experimental work was triangular, with 06 (six) cutting edges, model TNMG 160408, with TiAlN cover, nano structured by pvd method (steam physical deposition), CLASS ISO P25M25. For the fixation of the hard metal insert, the MTJNR 2020-K16 support was used, with a shank measurement of 20x20m and a total length of 125mm. The tool carrier used follows the international standardization of the dimensions of tools for turning, being compatible with the interchangeable insert [10].

For the application of fluids in the Form MQF, a micro-lubrication applicator was used, model accu-lube manufactured by ITW Chemical, with operation by means of a continuous flow to compressed air, adjusted around 6 Kg/cm², and intermittent fluid spray at the frequency of 1 pulse per second, adjusted to the flow of 90ml/h.

2.2 Surface roughness measurement system

The average roughness (R_a) was determined as a function of the mean line M of the roughness profile and the maximum roughness (R_y), defined as the highest value of partial roughness (Z_i) that is presented in the lm measurement path. They were measured on the machined surface of the part with the aid of a digital rugosimeter model TR220 from TimeGroup Inc., with resolution of 0.01µm and cut-off sampling length (le) of 0.25mm. Roughness was measured in 4 distinct points of the piece, using the midline method – M, as indicated by NBR ISO 4287/2002[11] and NBR 8404/1984[12]. In this system, all quantities are defined from a reference line, the midline, which is defined as a line arranged parallel to the general direction of the profile, within the measurement path, so that the sum of the upper areas, understood between it and the effective profile is equal to the sum of the lower areas. The roughness measurement scheme is shown in Figure 5.

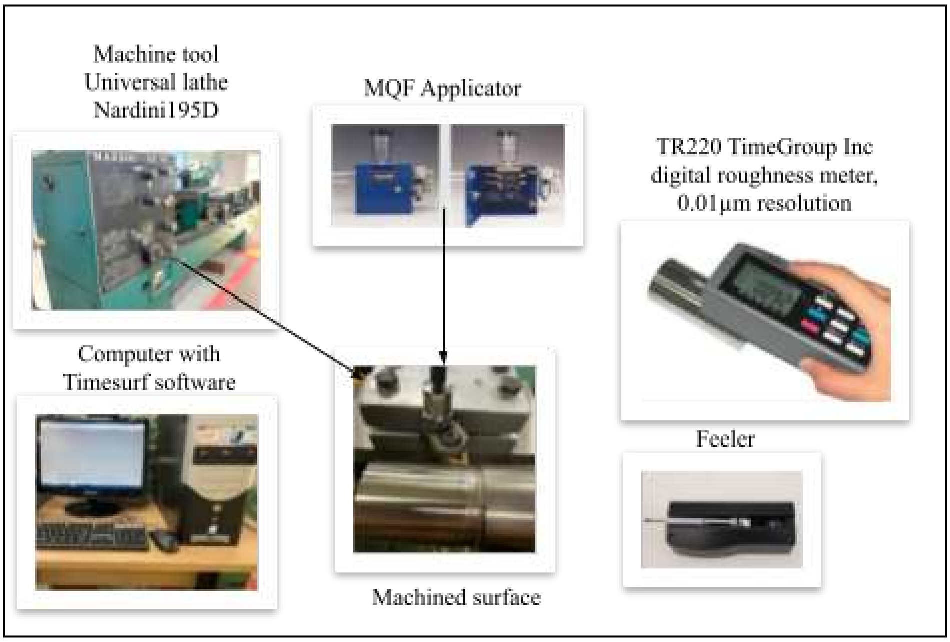


Figure 5: Surface roughness measurement system

III. RESULTS AND DISCUSSIONS

3.1 Effects of cutting parameters on average roughness

Surface roughness influences not only the dimensional accuracy of machined parts, but also their properties, being an important parameter to evaluate the performance of the cutting tool. The irregularity of a surface is the result of the machining process, including the optimal selection of cutting conditions[13]. According to the Pareto chart, shown in Figure 6, it is possible to identify the significant factors and non-significant factors of R_a analysis.

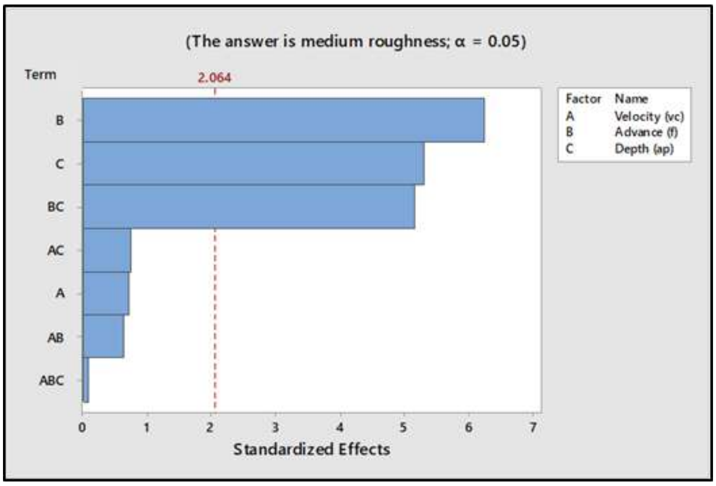


Figure 6: Pareto chart of standardized effects

Adopting a decreasing order we have the advance (f), the depth of cut (a_p) and the interaction between both (f x a_p) as statistically significant, that is, they present values of $p < 0.05$. The other factors contained in the graph are not statistically significant, i.e., the cutting speed (v_c) has little influence on the results obtained. According to Machado and da Silva.[14], advancement is the most influential parameter on roughness, followed by the tool's tip radius. In fact, there was an increase in roughness with the increase in advancement, and it was shown that roughness also increased considerably with increasing depth of cut. Therefore, to achieve lower roughness values, low feed values should be used, associated with low cutting depths, according to the pre-established parameters in factorial planning, which confirms the study presented by Xiao, Liao and Long[15], where the authors mention that when using high advance values, there is a sharp increase in roughness, since the chip tends to be pulled out rather than shear the material.

Therefore, it is important to ratify that proper selection of the advance is essential, because Trent and Wright[16] mention that the reduction of the advance in the turning process reduces the force applied against the cutting tool and in certain cases may compromise the stability of the machine tool system and induce vibrations, thus promoting the reduction of the quality of the surface finish. Kumar, Singh and Singh.[17] mention that several factors influence roughness in the turning process, including lateral chip flow, system vibration, material fixation on the machine, feed and cutting speed. This demonstrates how rough the surface depends on the tool feed (so called feed marks).

3.2 Analysis of the performance of plant fluids in relation to surface finish

The use of cutting fluids also effectively influences the surface finish of tools machined by the turning process, since it promotes a reduction in the machining forces generated and the softening of the vibrations of the machine tool set[2]. Figure 7 graphically shows the behavior of the average roughness (R_a) in relation to variations in cutting conditions and plant and commercial base fluids analyzed.

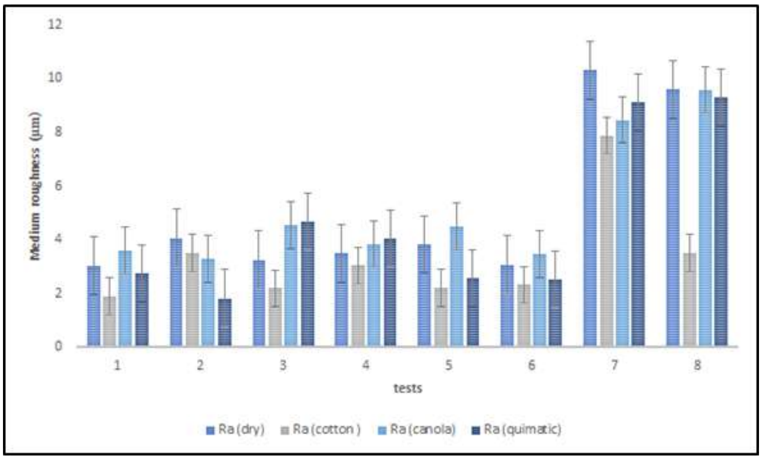


Figure 7: Performance correlations of cutting fluids in relation to average roughness

Figure 7 shows that in all cutting conditions, the dry condition presented the worst desem penho, significantly increasing the surface roughness in terms of R_a, obtaining inadequate surface finishing conditions. Araújo Junior[2] mentions that the good performance applied vegetable oils in the MQF form is justified due to its adequate heat removal and viscosity removal capabilities, which provides a better adhesion of the fluid in the tool part contact area.

To evaluate which vegetable oil presented a better performance in this stage, we used the statistical inference applied to the average roughness criterion, using the student's t-test for paired data (comparison between R_a obtained with application of vegetable oils, with R_a both of the dry condition and with application of the quimatic commercial oil), considering two hypotheses, one being null, where there is no significant difference between the roughness means and the other non-null conside that opposes the first. To define whether the null hypothesis should be rejected or not, a reliability of 95% or equivalently a significance level of 5% was adopted. That is, if the probability of the test (p-value) is less than this significance level, the null hypothesis is rejected. Otherwise, the null hypothesis will not be rejected. This analysis is presented in Table 3.

Table 3: Statistical analysis between vegetable oils in the mean roughness criterion using paired student t hypothesis test at significance level of 5% (α = 0.05)

Vegetable oil	Comparison α=0.05	
	Dry (p-value)	Comercial (p-value)
COTTON	0.032305	0.119406
CANOLA	0.666210	0.115701

When analyzing the comparison regarding the use of vegetable or dry oil, through the paired t-test, it was observed that for the criterion of average roughness (R_a) only cotton oil presents a significant difference between the means obtained (p-value<0.032305<0,05). In the vegetable x commercial comparison (quimatic), there is no significant difference between the means, that is, the type of cutting fluid did not influence the surface roughness.In this case, we chose to use cotton oil, because it presents satisfactory performance when compared to the dry condition and also does not produce harmful consequences for both operators and the environment. Figure 9 illustrates the boxplot graph for comparison between the means obtained in each condition.

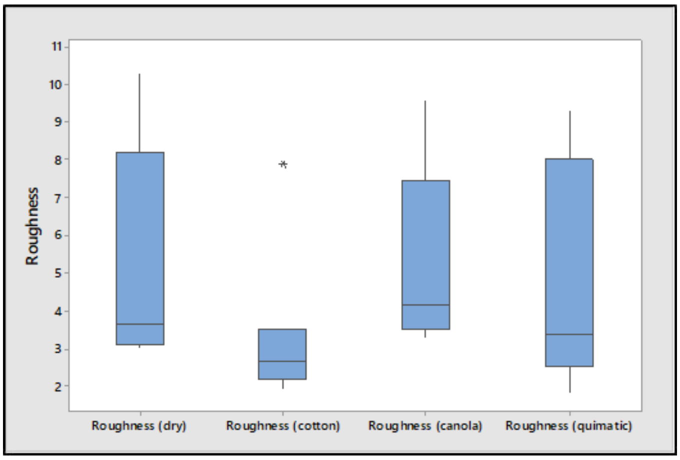


Figure 8: Boxplot for medium roughness (Ra)

Through Figure 8, it can be analyzed that the condition with the use of commercial oil quimatic presented greater variability. In the condition with the use of cotton oil, a superficial finish with lower roughness values was obtained, which confirms the study by Machado and da Silva[16], which reports that for warrant a good performance regarding the surface finish is necessary the appropriate choice of fluid, taking in consideration of the type of metal and the machining parameters.

IV. CONCLUSIONS

The advance proved to be a key parameter in obtaining a good finish in the process of external cylindrical turning of AISI 316 steel. Therefore, for each condition the choice of the correct feed must be made taking into account the material, tool and operation that will be performed on machining.

Cotton oil presented the best performance in relation to the criterion of average roughness (R_a), producing a surface finish of the piece suitable for the cutting conditions studied.

Thus, the use of vegetable cutting fluids proved satisfactory in relation to the superficial quality of the part, and can be used in external cylindrical turning operations, bringing to the industrial process characteristics of biodegradability, exemption from safety and physiological safety for operators. However, one disadvantage that can be pointed out is the presence of oil mist generated by the MQF application process.

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