CAPITULO 2

STUDY OF MACHINING FORCES IN FRONTAL MILLING OF STEEL WITH MQF APPLICATION OF VEGETABLE OIL (MACHINING FORCES IN FRONTAL MILLING)

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ABSTRACT: Machining forces are important in evaluating the effect of machining parameters. The machining force is resultant of forces acting on the cutting edge, and the determination of such is also important for the design of the machining equipment, tools and devices. The objective of this work is to evaluate the effect of the application of refined babassu oil (Orbignya oleifera), when used as cutting fluid with minimum amount of fluid (MQF) technique, in the machining forces of ABNT 1045 during frontal milling process. The methodology consisted of the application of babassu oil, comparing its performance with the commercial cutting fluid LB 2000, both in the MQF technique, and with the dry condition. It was carried out an Experimental Planning - DOE factorial 2^5, having as variables the cutting speed, feed speed, cutting depth and cutting fluid at various MQF flow rates, being analyzed the cutting forces, feed force and passive force. Babassu oil, besides ecologically correct, allowed values of machining forces lower than the dry condition and in line with the LB 2000 oil, being more efficient at 50 ml/h and 200 ml/h fluid flow rates.

KEYWORDS: Machining forces, cutting fluid, machinability, cutting parameters

INTRODUCTION

Machining forces are important in evaluating the effect of machining parameters. The machining force is resultant of forces acting on the cutting edge, and the determination of such is also important for the design of the machining equipment, tools and devices (Iturbe et al, 2017). Several works (Lee et al., 2017; El Hakim et al., 2015) have been carried out in the sense of using cutting force as a way to evaluate the machining process. These works have different approaches, where the cutting forces are correlated with parameters ranging from roughness, tool wear, to microstructure and mechanical properties (Binder & Doebbeler, 2017; Qiu et al., 2017). In general, the direction and way of the machining force (F) are difficult to determine, therefore it is decomposed into components. The components of F are identified by indices: "*c*" for the main cutting direction, "*f*" for the feed direction and "*p*" for the passive direction (perpendicular to the work plane). The cutting force "F_c" has the same direction and way of the cutting speed "V_c". It is responsible for most of the cutting power. The feed force "F_f" has the same direction and way of the feed speed "V_f", causing tool deflection. The passive force "F_p" is the component of F perpendicular to the working plane P_f. Figure 1 shows the direction of the components of the machining forces.

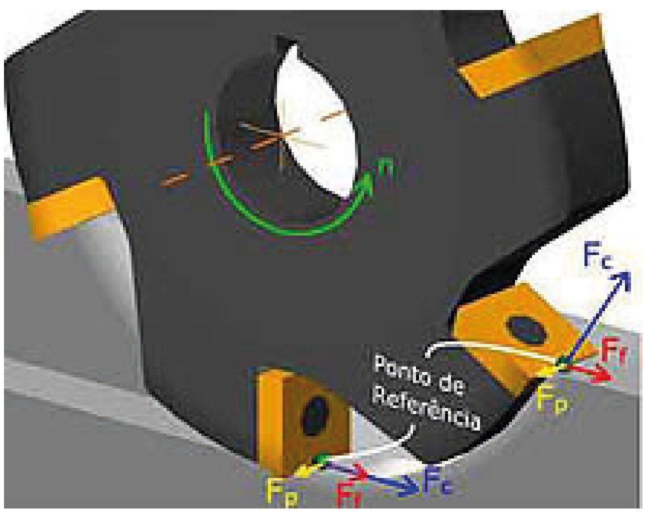


Figure 1 - Decomposition of the force in its components F_c, F_f and P_f

In order to reduce machining forces, improve tool's life, surface finishing, improve dimensional accuracy, improve the breakage and transport of chips, as well as to protect the machined surface and tools from oxidation, the use of cutting fluids play important role (Machado et al., 2009). The cutting fluids have several functions in the machining processes, such as acting as cooler for the cutting region (notably at high cutting speeds) and/or lubrication (notably at low speeds and at high cutting stresses).

The discard of cutting fluids is an undesirable process, mainly because it is a pollutant and requires complex and costly prior treatment. Regarding to the destination of these products, environmental legislation establishes criteria according to the characteristics of the liquid reject, which take into account parameters such as sedimentable residues, pH, dissolved oxygen, chemical and biochemical demands of oxygen, temperature, oils and greases and the presence of microorganisms (Shokoohi et al., 2015).

Many aspects of environmental problems associated with cutting fluids can be avoided or minimized by investing in research to develop new types of fluids and less aggressive methods of application, as well as promoting trainings leading to a better understanding of the impacts caused by the undisciplined use of the cutting fluids and promote environment-friendly practices. The introduction of the series of environmental legislation, OSHA (American Occupational Safety and Health Administration) and other international regulatory authorities have made the manufacture industry to reduce the consumption of mineral oil as cutting fluid for machining work, with great potential for the use of vegetable oils as cutting fluids for the sector (Burton et al., 2014).

Several works are underway to develop environmentally correct cutting fluids based on various vegetable oils, most of the work reported put in evidence soybean oils, sunflower oils and canola oils. Currently, many groups are involved in the development of vegetal-based oils as cutting fluids (Shyha et al., 2015; Shashidhara & Jayaram, 2010). The use of the Minimal Quantity of Fluid (MQF) has proved to be a very advantageous alternative in regards to abundant application of fluid in the machining, especially in the milling process. This technique consists in the use of a small amount of lubricating oil, which is sprayed into the cutting region. This way, the consumption of cutting fluid is significantly lower. For the MQF technique, the fluids used are generally vegetal-based with incorporated additives, and may also be of mineral-base. Figure 2 shows an example of milling process with the fluid spraying over the cutting region.

Figure 2 - Milling process using MQF technique

The objective of this work is to verify the influence of the babassu oil (Orbignya oleifera, Figures 3 and 4) when used as cutting fluid through MQF in the cutting forces for ABNT 1045 steel during front milling process. This work aims to contribute mainly to the dissemination and use of ecologically correct cutting fluids that can be used in the machining processes. Babassu seed oil has properties similar to palm oil, with a high content of lauric acid, being also suitable to several applications like cosmetic industry, food, soaps, detergents, lubricants, among others.

Figure 3- Babassu seeds

Figure 4- Babassu palm

MATERIALS AND METHODS

The methodology for the development of this work consisted of application of the vegetal-based cutting fluid (babassu oil), comparing its performance with the commercial oil LB 2000 (also vegetal-based, indicated for machining of ferrous metals, produced by ITW Chemical Products Ltda.) and with dry condition. An Experiment Planning – Factorial 2^5 was prepared, where the input variables were the cutting speed (V_c) of 165 and 210 m/min, the feed rate (f_z) of 0.15 and 0.3 mm/tooth, cut depth (a_p) of 1 and 2 mm, and pre-determined MQF flow rates (10, 50, 100 and 200 ml/h). The measured output variables were cutting force (F_x), feed force (F) and passive force (F_z). Table 1 highlights the planning.

Input Variables or Input Factors Material of part: ABNT 1045 steel; Cutting tool: Frontal cutter Coromil 345 with carbide-coated inserts (MW 4240) - Sandvik Coromant;Machine Tool: Discovery 560 (Romi); Working penetration (ae): 62 mm.				**Output Variables/Process Responses**			
Expt. No.	Cutting Conditions			Flow rate MQF (ml/h)	Machining forces (N)		
	v_c (m/min)	f_z (mm/tooth)	p (mm)		x	y	z
01 to 04	165	0.15	1	10			
				50			
				100			
				200			
05 to 08	210	0.15	1	10			
				50			
				100			
				200			
09 to 12	165	0.30	1	10			
				50			
				100			
				200			
13 to 16	210	0.30	1	10			
				50			
				100			
				200			
17 to 20	165	0.15	2	10			
				50			
				100			
				200			
21 to 24	210	0.15	2	10			
				50			
				100			
				200			
25 to 28	165	0.30	2	10			
				50			
				100			
				200			
29 to 32	210	0.30	2	10			
				50			
				100			
				200			

Table 1- Planning matrix for machining forces analysis

MACHINING FORCE MEASUREMENT SYSTEM

In order to avoid systematic errors, the manufacture and fixation of the pieces were standardized, being previously machined in a rectangular prism format with final dimensions of 180 mm length, 77 mm height and 62 mm width. Two holes of 15.25 mm (5/8") diameter each were made in order to fix the piece in the stationary dynamometer.

To acquire the machining forces, a Kistler 9257-B dynamometer was used attached to the machining central bus. The acquired signals are sent to a load amplifier and to an analog-digital conversion board (Measurement Computing USB 1208SF model, 1.25 MS/s). A computer using Delphi 7.0 software manages the signal. The methodology for capturing the force signal is shown in Figure 5:

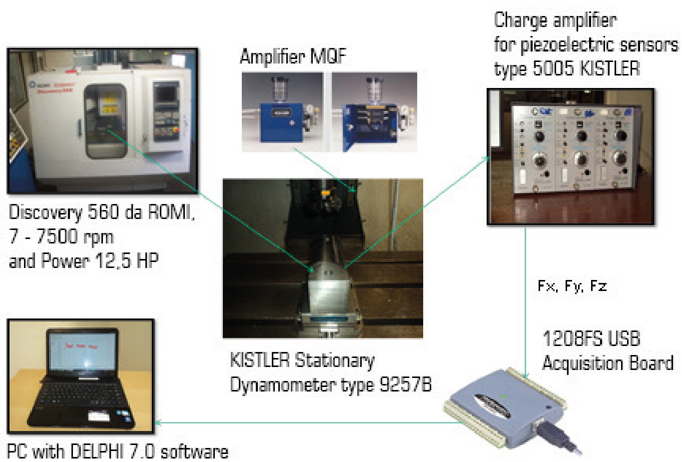


Figure 5 - Machining forces acquisition system

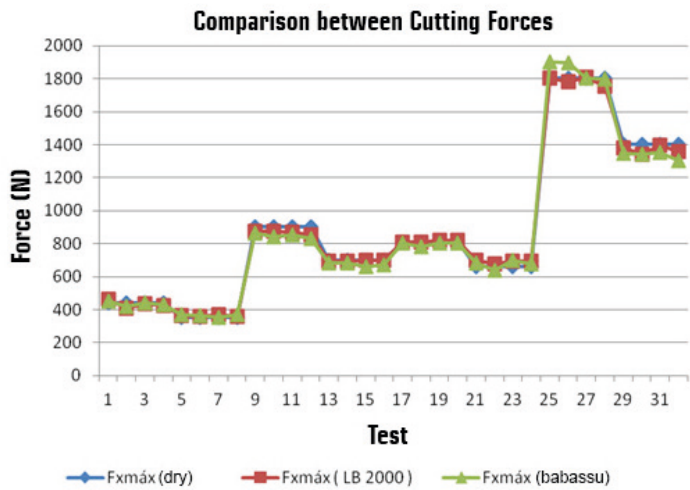
Tooling Characterization

The tools used for the front milling process are the following: Milling tool 345 - 080Q27 - 13M (Sandvik - Coromant) - Diameter of 80 mm and capacity for 6 inserts (only one insert was used in order to save materials and tools);Insert 345r - 1305M - PM 4220 (Sandvik - Coromant); and Cone 52.33.527 (Sandvik - Coromant).

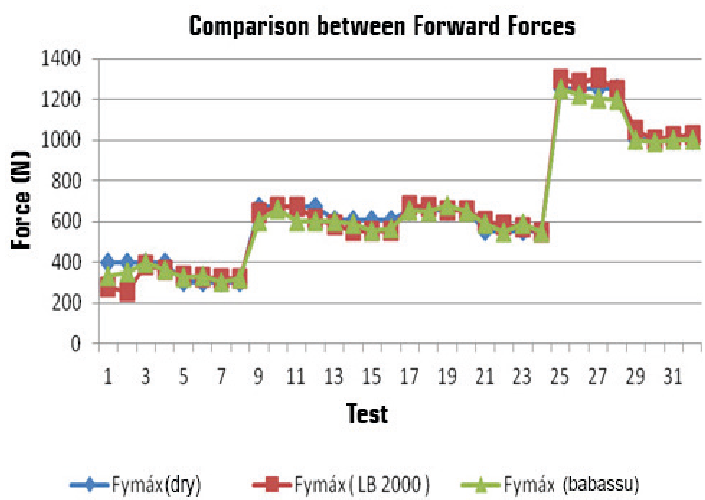
RESULTS AND DISCUSSIONS

The results obtained during the experiments show that, depending on the machining conditions adopted during frontal milling, there was a significant difference between them by varying the cutting speed (V_c), feed rate (f_z), cutting depth (a_p), cutting fluid application (babassu oil and LB 2000) and method (MQF), at the determined flow rates and dry condition.

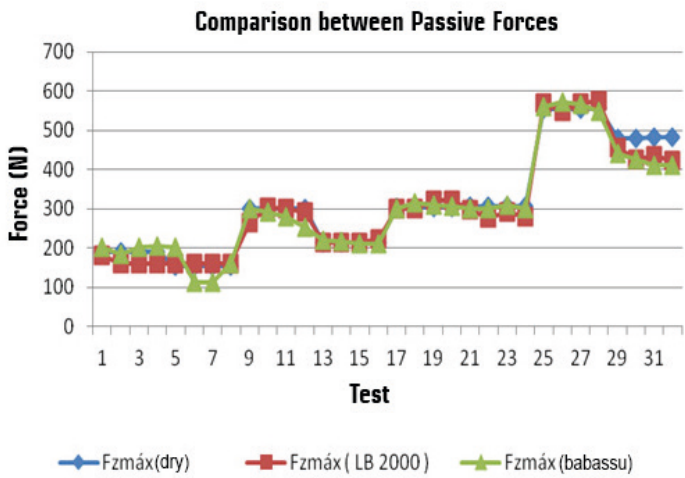
Through machining parameters was observed a moderate influence of the vegetal-based fluids application, by the slight reduction of the cutting forces in comparison with dry milling. Also is noticed a balance between the two cutting fluids applications, with their values of machining forces very close, practically in line. These results are presented in Graphs 1, 2 and 3. The machining conditions are those shown on Table 1.



Graph. 1- Comparison of cutting forces (F_{xmax}) under different conditions



Graph. 2- Comparison of the feed forces (F_{ymax}) under different conditions



Graph. 3- Comparison of the passive forces (F_{zmax}) under different conditions

By comparing the three results presented, is verified that the participation of the cutting fluids during the tests allowed a small reduction of machining forces. In the tests from 09 to 12 and from 29 to 32, with the variation of the cutting speed (V_c) and the depth of cut (a_p) at the same feed rate (f_z), there was a reduction in cutting forces (F_x); for the tests ranging from 01 to 04 and 13 to 16, with feed rate variation (f_z), for a same cutting speed (V_c) and depth of cut (a_p), there was a reduction in the feed forces (F_y); also there was a reduction of the passive force (F_z) in the tests of 29 to 32, for the most critical conditions of V_c, and a_p.

In the results quoted above, the effect of the cutting fluids (applied by the MQF technique) on machining forces is observed, that is, its lubricant-cooling function minimizes the effect of temperature fluctuation in the tool during the cutting process.

The analysis of variance (ANOVA) of the results indicates that, with a confidence interval of 95% and an alpha significance level of 0.05, the lubrication condition has a significant influence on the reduction of the machining forces, as shown on Table 2.

Variable		P - Value	Variable	P - Value	Variable	P - Value
Dry			LB 2000 Fluid		Fluid Babassu	
Fx		> 0.05	Fx	0.000220	Fx	0.000315
Fy		> 0.05	Fy	0.000438	Fy	0.000494
Fz		> 0.05	Fz	0.00326	Fz	0.00716

Table 2. Experiment analysis with two factor levels 2 ** (4 - 0)

CONCLUSIONS

The results presented allowed some conclusions, considering the testing conditions:

The cutting forces were greater for the critical condition, where the maximum cutting conditions were used (V_{cmax}, F_{xmax} and a_{pmax});

The babassu oil used as cutting fluid presented similar results to LB 2000 fluid and better performance when compared to dry conditions, which leads us to believe that it can become a potential substitute for other machining fluids.

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