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MOISTURE CONTENT OF WOOD AND CUTTING POWER IN THE UP MILLING ARE CORRELATED SIGNIFICANTLY

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Abstract. *The surface quality machined wood suffers the influence of various factors, and among the main, the moisture content of this material stands out with one of the most difficult to be controlled because it consists of a hygroscopic material, having strong interaction with moisture from the environment around its. Different methods of measurement are used in the study of the influence of process variables on surface quality of wood, in academia, the method of mechanical contact is one of the most commonly used methodologies, however, for an application on an industrial scale, it is necessary to look for alternatives and/or helper methods that might indicate decreased quality of wooden surface, with higher speed and in real time. One alternative would be the use of indirect methods of measuring quality that correlate with any process variable, as for example, the study of the variation of the energy consumed during the machining process. Knowing that the surface quality machined wood suffers the influence of moisture content, objective with this work to was to analyze the possible correlation between different levels of moisture content from the wood of the species Pinus elliottii and the variation of the energy consumed during up milling. The samples of wood were packed in automatic greenhouses to obtain different levels of moisture content (varying between 8 to 21 percent). For machining the samples of evidence was used a machining center with numeric control that works solely with wood or materials with similar physical attributes. The machining center was equipped with a tungsten carbide cutter. The power consumed values were obtained instantly with the aid a module of channels of brand National Instruments. It was observed a statistically significant correlation, at a significance level of 5 percent, showing a trend of increase of power consumption during up milling with increasing moisture content, however obtained a coefficient Pearson correlation of 0.331 with p-value of 0.049.*

Keywords: *Surface quality, Wood machining, Methods of measuring.*

1. INTRODUCTION

For Saloni, Lemaster and Jackson (2010) machining in materials not homogeneous like wood, has its degree of complexity of process increased.

The moisture content present in the structure of the wood is one of the variables that most influence the finish of the machined wood. Control of the moisture content of the wood is an act of extreme importance, as it helps in decreasing the machining defects such as rough fiber or chipping the edges of the wood finished, among other defects.

For Gonçalves (2000) there are several factors that interfere on the strength and power machining in different wood cutting operations, affecting the cutting performance of the tools, such as moisture content, density and direction of the fibers (referring to wood) and cutting thickness, cutting speed and tool geometry (referring to the process).

It is possible to quantify the influence of the variation of the moisture content of wood in its machining, performing the characterization of the quality of the finish, and for this, there are several possible methods for this determination, each with a specific characteristic.

According Elmas et al. (2011) profile measuring systems for surface characteristics can be divided into two main groups - the contact and non-contact methods.

For Elmas et al. (2011) the most common method of obtaining surface profile data, considering direct contact with the workpiece, is the use of mechanical counting from the end of profilometer over the entire surface, tracing the tip movement for profile information.

According to Islam et al. (2011) Jeyapoovan and Murugan (2013) surface profile measuring systems have been widely used in various industrial processes for the assessment of surface finish and cutting tool wear.

For Kilic, Hiziroglu and Burdurlu (2006) one of the main advantages of cutting-edge profiler method is presentation of the real profile of numerical roughness parameters of the surface. Any type and magnitude of the irregularities in surface roughness can be objectively quantified by this method.

Jeyapoovan and Murugan (2013) argued that despite the tip profilometer conventionally be used in the measurement of surface roughness, this method is not suitable for measurements in the production line, as this measurement process is invasive and contact type . There is a growing need for a reliable method, online and contactless for surface measurements.

Zhong, Hiziroglu and Chan (2013), Hiziroglu et al. (2013) and Ayrilmis, Benthien and Thoemen (2012) state that currently there is no standard accepted method to determine the roughness of the surface of wood and wood-based products.

According to Zhong, Hiziroglu and Chan (2013), the roughness of the surface of wood and timber products can be readily determined using various numerical values with indirect techniques.

According to the arguments of Elmas et al. (2011), concerning the characterization of the method of machining non-contact surface, most methods are based on optical methods. These methods include optical profilômetros (mainly based on laser method), microscopes, image analyzers, imaging spectrographs, interferometers, optical transducers, white light patches, the laser scattering, the light sectioning optical systems, etc. However, the methods cited by these authors may have a basic inconvenience, from the anatomical characteristics of wood, such as pores and vessels. Optical methods tend to measure these depths that are inherent in the wood anatomy and, therefore, were not caused by the interaction of the cutting tool and the wooden workpiece, overestimating the roughness caused by the machining process.

In the literature there are no studies that deal with the roughness on surfaces planed considering different moisture contents of raw materials, as suggested by Kilic, Hiziroglu and Burdurlu (2006) and Aknouchea et al. (2009), logs early and late, and the sense of machining.

Analyzing the advantages and disadvantages of the profile measuring systems for surface characteristics contact methods mainly the tip profilometer and without contact, optical methods, it is noted that other ways of determining the quality should be studied, taking into consideration key points, such as roughness measurement speed that meets the dynamics of industrial production and the correct determination of roughness originated from the interaction of the cutter with the wood part, not the characteristic measurements that add porosity of the wood.

As commented by Gonçalves (2000), between the various factors that influence on the forces and power machining in different wood cutting operations, is included moisture content. Using this correlation may be possible to use other indirect, quickly and accurately to quantify the surface quality of the wood after machining. Therefore, knowing the quality of the machined surface of the wood is influenced by moisture content, the objective of this study was to analyze the power of the variation consumed during up milling the wood of the species *Pinus elliottii*, for different moisture levels of wood by checking whether there really is a correlation between these variables and you can use it as an indirect means for online prediction of the wood quality.

2. MATERIAL AND METHODS

2.1 Preparation of specimens

Of a batch of lumber, coming from the *Pinus elliottii* were randomly selected eighteen tangentially sawn boards in relation to growth rings with dimensions: (3000 x 148 x 25 mm), with an average moisture content of 14.4%. Defects without Seventy-two specimens with nominal dimensions (315 x 65 x 23) mm (Fig. 1) of the boards were removed and divided equally into three groups. Then, each group containing twenty-four specimens were placed in greenhouses with automatic climate control (Fig. 2) in order to obtain specimens with moisture contents distributed in three wood moisture content classes (Moisture Content (MC)): 1st class: 8 ≤ MC <12; 2nd class: ≤ 12 MC <16 and 3rd class: ≤ 16 MC <20, performing a humidity control and temperature to obtain the required moisture content. They were obtained specimens with moisture content between 8 and 20%.

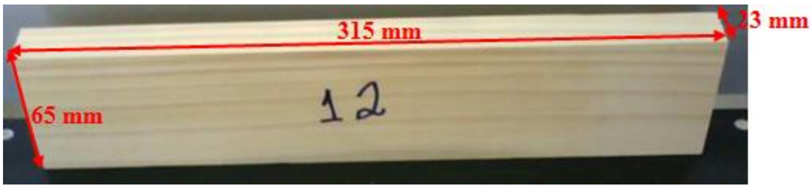

Figure 1. Dimensions of the specimens (315 x 65 x 23) mm.

Figure 2. (a) Automatic climate control used in obtaining the moisture classes; (b) Automatic climate control Display indicating the temperature and relative humidity, respectively.

2.2 Equipment and procedures used in machining test

Twelve specimens of each conditioned moisture content class were randomly selected. Twelve specimens of each class were randomly machined in a wood machining center (Fig. 3), with six replications machining by specimen.

Figure 3. Wood machining center

The wood machining center was equipped with a tungsten carbide cutter (HWM) - Premium – Up Cut Spiral Bit (Fig. 4), D = 16 mm, L = 90 mm, 35 mm I = S = 16 mm, with three positive helical cuts.

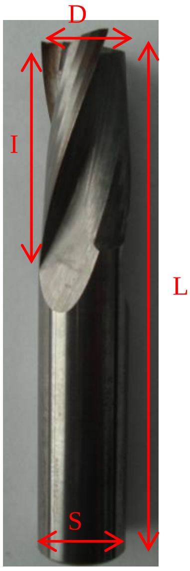

Figure 4. Tungsten carbide cutter with helical cuts to finish. Identification of their basic dimensions (D, L, I e S)

Machining tests were from the pre-established parameters, as shown in Tab. 1.

Table 1. Parameters used during up milling process.

Parameter	Value	Unit
Tool rotation	15000	rotation per minute
Depth of cut	1	millimeter
Diameter of the tool	16	millimeter
Cutting speed	753.6	meters per minute
Advance speed	2	meters per minute
Feed per tooth	0.04	millimeter
Cutting width	30	millimeter
Ra theoretical	0.022	micrometro
Rt theoretical	0.031	micrometro
Lateral wedge angle of the tool	66	degrees
Side exit angle of the tool	20	degrees
Side clearance angle of the tool	4	degrees
Helix angle of the tool	20	degrees

The power consumed during machining was obtained by capturing the variation of the electric current using a current transformer, a decrease of 25 Amperes to 5 Amperes (Fig. 5a) this transformer has reduced the current that was collected by the sensor Hall effect (Fig. 5b). The Hall effect sensor is connected externally to the motor power cables responsible for the rotation of the tool for capturing the variation of the electric current.

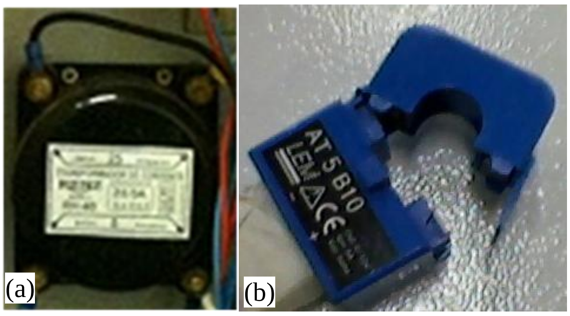

Figure 5. (a) current transformer; (b) Hall effect sensor.

The variation of the electric current in the machining was acquired instantly for each machined specimen will a rate of 400 points per second through the Hall effect sensor installed on the machining center. The Hall effect sensor channels module is connected to a brand National Instruments (Fig. 6 b), and connected to this data acquisition sign brand NI (Fig. 6 c) inserted data acquisition computer located at the side of the machining center (Fig. 6 a). The acquired signals across the board were processed and stored through a pre-prepared program in LABVIEW software version 7.1 (Fig. 6 d).

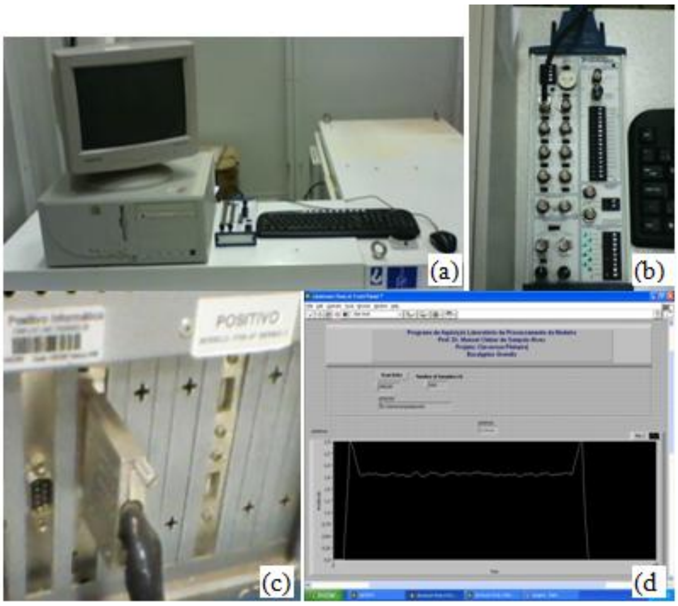

Figure 6. (a) computer for data acquisition; (b) channel module; (c) data acquisition card and (d) software LabView screen, with the electrical current signal being collected.

Power machining was measured experimentally by means of voltage and electric current consumed. The apparent power for three phase motors was calculated by Eq. (1).

$$P_{ap3F} = U \times i \times \sqrt{3} \times \cos\varphi \qquad (1)$$

Where:
P_{ap3F} = apparent power for three phase motors, in Watts;
U = voltage of the phases, in volts;
i = alternating current one phase, in Amperes;
cos φ = power factor.

As the signal acquired by the system has a proportional output in Volts it was necessary to convert the value to volts Amperes so that it could use Eq. (1). And it was necessary to use a reduction of current transformer 25A / 5A, the UCC variable was multiplied by 5. The transformation of Volts to Amperes was performed with the aid of Eq. (2).

$$i = \frac{U_{cc}\ x\ 5}{2} \qquad (2)$$

where:
i = current in Amperes;
U_{cc} = direct current voltage, in Volts.

Substituting the current value obtained by Eq. (2), the value of the motor phase voltage of the tool (220 V) and power factor (0.92) of the engine, resulting Eq. (3).

$$P_{ap3F} = \frac{U_{cc}\ x\ 5}{2} \times 220 \times \sqrt{3} \times 0{,}92 \qquad (3)$$

3. RESULTS AND DISCUSSION

The Figure 7 shows the scatter plot used to study the correlation between the moisture content of wood and power consumed during the up milling. A trend of increased power consumption with the increase in wood moisture content can be observed.

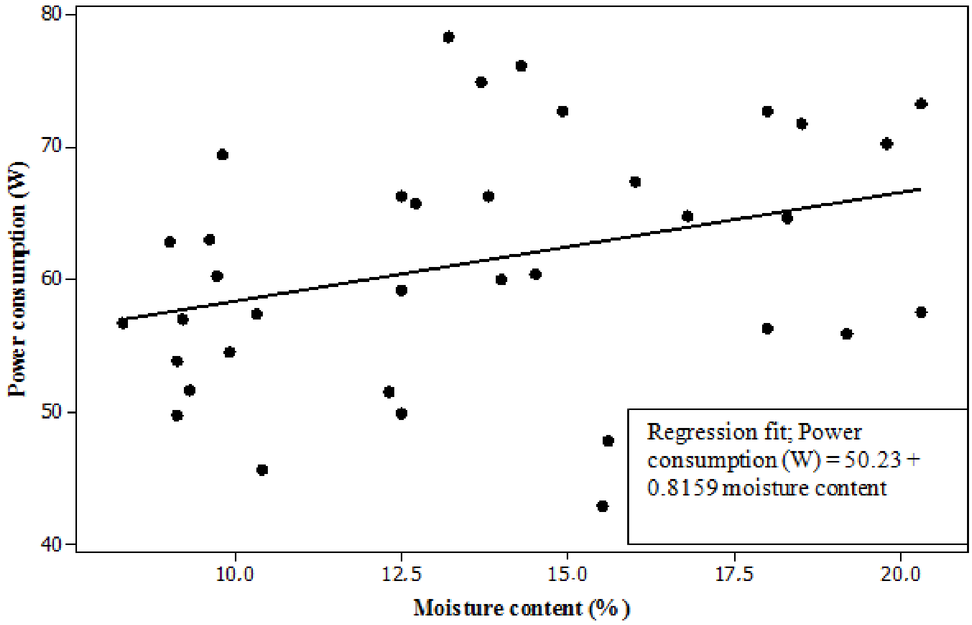

Figure 7. Scatter plot for Power consumption and moisture content.

The Table 2 shows the coefficients (Coef) the line adjusted for the relation between consumed power and moisture content, the standard deviation of coefficients (SE Coef) and the statistic t values and the value of p-value (P) . In a level 5% of significance, it can be seen that the adjusted linear regression equation is statistically significant, since value p-value for the Constant and the moisture content is less than 5%.

Table 2. Coefficients of the adjusted regression equation.

Predictor	Coef	SE Coef	T	P
Constant	50.227	5.643	8.90	0.000
Moisture content	0.8159	0.3996	2.04	0.049

The Pearson correlation of moisture content (%) and power consumption (W) was of 0,331. Analyzing person correlation coefficient this value is noticed that there is a low correlation between the variables studied, however as seen by Tab. 2, the calculated value of p-value is less than 5%, that considering a significance level of 5% can be concluded that there is sufficient evidence to state that the power consumed and wood moisture content are correlated.

The Table 3 shows the analysis of variance (ANOVA) for the linear regression between variables. It can be seen that at a significance level of 5%, the fitted regression is statistically significant.

Table 3. Analysis of variance (ANOVA).

Source	DF	SS	MS	F	P
Regression	1	323.23	323.23	4.17	0.049
Residual Error	34	263.60	77.52		
Total	35	2958.83			

Despite the low correlation between the variables, it is observed that this correlation is statistically significant, but the change in power level consumed may not have sufficient sensitivity to help forecast the level of quality of wood machined.

4. CONCLUSIONS

The conclusions about the results can be analyzed as follows:

The Pearson correlation of moisture (%) content and power consumption (W) was 0.331.

Considering a 5% significance level, we can conclude that there is sufficient evidence to state that the power consumed and wood moisture content are correlated;

The change in power level consumed may not have sufficient sensitivity to help forecast the level of quality of wood machined.

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