Analysis of the Cutting Parameters in Front Milling for Medium Density Fiberboard

Priscila R. Deus,[a,]* Manoel C. S. Alves,[b] Fabio H. A. Vieira,[a] and Luciano R. Bilesky [a]

Medium density fiberboard (MDF) is an industrial product manufactured from lignocellulosic fibers. It has homogeneity, dimensional stability, and mechanical strength compared with solid wood. Milling is a machining method widely used in the furniture industry; despite the relevance of the subject, there are few works dealing with the specific MDF milling process using computerized numerical control (CNC) machines. This study evaluated MDF milling in CNC machining centers by analyzing roughness. The MDF panels were front direction with the machined cut depth of 3 mm with six replicates, four cutting speeds of 804 m/min, 603 m/min, 402 m/min, and 201 m/min, and one forward speed of 4 m/min. The parameter of roughness average (R_a) was analyzed. The results showed that the surface roughness showed lower values for the cutting speeds of 603 m/min and 804 m/min, and cutting depths of 3 mm exhibited satisfactory results for the front surface. In conclusion, the parameters studied here significantly influence the finish, resulting in uneven surfaces that can reduce the quality of products.

Keywords: Panels; Roughness; Finishing wood; Wood

Contact information: a: Faculty of Technology, Department of Forestry, Capão Bonito, SP, Brazil; b: Mechanical Engineering Department, UNESP, Guaratinguetá, SP, Brazil;
** Corresponding author: priscila.roel@fatec.sp.gov.br*

INTRODUCTION

Technological advancement in industry produces quality materials with low cost and high productivity. The growth of the timber industry requires technological innovations, but the peculiar anatomy of wood requires intense research to develop these processes.

Machining in wood can affect the tool life, productivity, and piece quality. Therefore, it is important to know the physical and anatomical properties for correct use (Lucas Filho 2004). The use of suitable machining techniques for the transformation of wood can minimize and even correct problems due to its variability (Zamarian *et al.* 2012). There are important variables for machining that influence the surface quality, cutting speed, feed rate and cutting depth (Pinheiro 2014). New machining technologies make it easier to obtain high-quality finished products from materials that are otherwise difficult to machine. One of these processes is computerized numerical control (CNC) (Machado *et al.* 2009).

Currently, there is a wide technology and a variety of machining operations for milling. With CNC, it is possible to conceive complex designs sometimes impossible to be made by conventional cutting methods, while also minimizing costs, production time and material (Barata *et al.* 2016).

Front milling is characterized by obtaining a flat surface on the workpiece, which is perpendicular to the tool rotation axis (Ferraresi 1977; Maia 2009; Diniz *et al.* 2013).

An uneven surface after machining reduces the final product quality. This characteristic is defined by measuring the roughness of medium density fiberboard (MDF) panel pieces. In this way, it is possible to quantify the surface quality and improve the machining process through cutting speed and feed rate.

Rossi *et al.* (2005) compared the relationships between the cutting parameters and the roughness of metals through milling. Two rotations (n) of 224 and 710 rpm were used for two feed rates (f) of 25 and 78 mm/min and two machining depths (A_p) of 1 mm and 6 mm. The cutting parameter that most influenced the roughness was feed rate, followed by the rotation, and finally, the machining depth.

By investigating the influence of cutting speed and feed rate parameters through surface roughness in MDF, Davim *et al.* (2009) observed that the surface roughness decreases by increasing the spindle speed and increases with feed rate. MDF milling shows the advantage of using a high feed rate. The machining depth and roughness of the surface are changed according to the workpiece and the machining parameters within the process. Therefore, it is important to investigate the milling performance in different operating parameters to find the best roughness condition and machining depth (Davim *et al.* 2009).

A high-quality machining surface is important because it influences the cost of the final product, especially for high durability materials (references). Thus, milling operations are almost indispensable, consuming a great deal of processing time and having a significant impact on the surface finishing quality and on the final product costs (Chen *et al.* 2012).

The quality of the milled surfaces depends on the degree of roughness. What influences the quality of surfaces are the technological parameters and the characteristics of the material. Depending on the machining methods, the surfaces present a specific roughness, even when the parameters used are the same (Sedlecky 2017).

The objective of this work was to evaluate MDF surface roughness after frontal milling with different cutting parameters (cutting speed and cutting depth).

EXPERIMENTAL

Materials

Duratex medium density fiberboard – MDF with 15 mm thickness and coated board was supplied by a manufacturer in Itapeva, São Paulo, Brazil. The panel of MDF obtained the average basic density of 736 kg/m^3 and average humidity of 8.33%.

The frontal milling was carried out to generate 6 machined reps for each different cutting speed (S_c) of 201, 402, 603 and 804 m/min, at 4 m/min feed rate and three different machining depths of 3, 6 and 9 mm, covering 100% of the piece and totaling 6 parts for each depth (Fig. 1). The entire experiment was carried out in a machining center with CNC model TECH Z1 SCM brand. This machine works only with wood or materials with similar physical attributes.

The milling cutter used was the "top" integral carbide cutter for finishing, with three HWM-Premium-Upcut Spiral Bit, with 16 mm diameter, 90 mm length and an I value of 35 mm with three positive helical cuts.

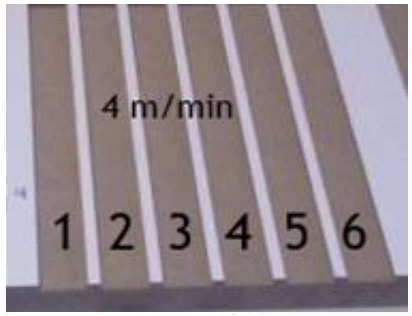

Fig. 1. Machined specimen - front milling

To measure the average roughness of the pieces represented by the average roughness parameter (R_a), a Taylor Hobson rugosimeter (Surtronic 25 model) was used in Itapeva, SP, Brazil with diamond cone-spherical probe tip, 2 μm tip radius (Fig. 2). The rugosimeter parameters were 2.5 mm cut-off, 12.5 mm length, robust Gaussian filter, and 300 μm range (resolution). The prioritized measure (R_a) parameter is given in units of micrometers (μm).

Fig. 2. Roughness meter SURTRONIC 25 (a) overview and (b) measuring rod

A Zeiss EVO LS-15 scanning electron microscope (Oberkochen, Germany) with openings for extended pressure (EP) mode was operated under N_2 atmosphere at 5 kV (low voltage). The pressure was set to 60 Pa, and the backscattered electron signal was collected with a VPSE-G3 detector.

For all cutting parameters, a Tukey statistical test was performed with Minitab software (State College, PA, USA).

RESULTS AND DISCUSSION

Roughness Analysis (R_a) in Relation to Cutting Speed (S_c) and Cutting Depth (A_p)

The ANOVA test for the velocity of 4 m / min in the frontal milling for the average values of Roughness (R_a) indicate coefficient of variation of 11.42%. The machining depth (F_{ap} = 4.03; p-value> 5%) and the depth and shear rate ratio ($F_{ap\ x\ CS}$ = 30.64; p-value> 5%) show statistically significant results. The relationship between the cutting speed and the machining depth with $F_{Cs\ x\ ap}$ = 2.12; p-value> 5% did not present significant results.

The average roughness (μm) values for the cutting speeds 201, 402, 603, and 804 m/min through Tukey test, with 95% confidence, are described in Table 1. The cutting depths (A_p) 3, 6, and 9 mm with Tukey test are described in Table 2. Both had a 4 m/min feed rate.

Table 1. Tukey Test for Cutting Speed

S_c (m/min)	R_a (μm)	Tukey
201	13.21	A
402	11.36	B
603	10.83	B
804	9.76	B

Table 2. Tukey Test for Cutting Depth

A_p (mm)	R_a (μm)	Tukey
3	9.01	B
6	12.26	A
9	12.61	A

The surface roughness analysis for the parameters of cutting speed and cutting depth for frontal direction showed the tendency of better results with higher cutting speeds and lower cutting depths. The Tukey test demonstrated that there were significant differences only when the cutting speed was very low (201 m/min) and also highlighted that a smaller cutting depth resulted in a more homogeneous the surface.

Through the CNC milling of wood, a study pointed out that the most satisfactory results in relation to surface roughness are those related to higher cutting speeds (Eyma *et al.* 2004). When investigating wood shaving machining, high values of cutting speed demonstrated more satisfactory results (Valarmathi *et al.* 2013). For wood, the best results of surface quality were with higher cutting speeds, between 1131 m/min and 1234 m/min (Braga *et al.* 2014).

Figure 3 shows that the lowest roughness (μm) results were found in the cutting depth of 3 mm and cutting speed of 804 m/min.

When a cutting speed has been increased and the feed rate has been maintained, it is known that the cutting power and the stiffness of the cutting tool will influence the roughness of the workpiece. At high cutting speeds, the surface roughness presented better results as the tool passed through the machined surface various times. It was also possible to observe the formation of continuous chipping, that is, the machining was occurring continuously with lesser machine-piece impact.

Because MDF has compacted fibers in its constitution, the formation of the discontinuous chips resulted in a rough surface. High cutting speeds resulted in better finishing results. With high cutting speed values, each milling-cutter tooth removed less material, resulting in less vibration, and at the same feed rate conditions provided fewer rough surfaces. Therefore, with lower feed rate and higher cutting speed, the MDF surface tends to have less roughness.

The A_p parameter has little influence on the R_a value in metal milling (Rossi *et al.* 2005). However, in the current work with MDF, the three feed rates of 2, 4, and 6 m/min resulted in lower roughness values in the lower machining depth of 3 mm.

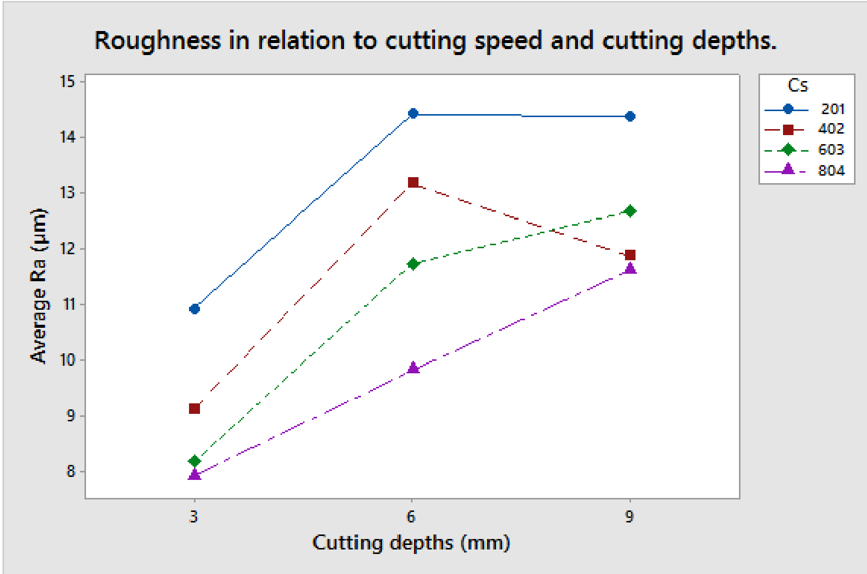

Fig. 3. Roughness (µm) with respect to S_c and A_p

Under these conditions, significant differences were observed. In MDF milling, the lowest roughness values occur at a machining depth of 3 mm (Castro and Gonçalves 2002).

The cutting depth has variable effects on roughness. Chen *et al.* (2012) found that greater rotation combined with greater depth results in decreased roughness. Other studies showed that cutting depth has no influence on roughness (Ueda *et al.* 2001; Savas and Ozay 2007). Finally, Rossi *et al.* (2005) reported that a cutting depth of 1 mm produces the lowest roughness.

Scanning Electron Microscopy (SEM)

In frontal milling, the MDF specimens chosen for SEM image analysis were tested with cutting speeds of 804 and 402 m/min and feed rate of 4 m/min and with three different machining depths, namely 3, 6, and 9 mm. Figure 4 shows that in 3 and 6 mm cutting depths, the fibers were cross-linked and agglutinated with a more homogeneous texture, without many grooves and fragmentations.

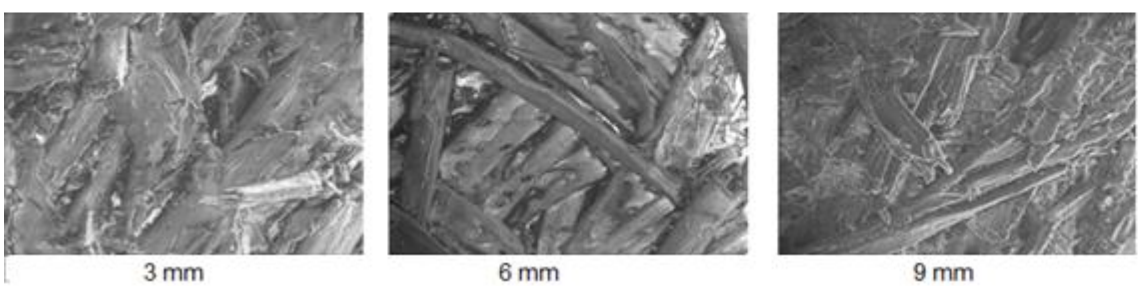

Fig. 4. Cutting depth of 3, 6, and 9 mm for the cutting speed of 804 m/min

At the speed of 402 m/min the fractured fibers increased, but still, it was observed that the fibers were compacted and had a more homogeneous texture in smaller cutting depth, as shown in Fig. 5. There was an increase of fibers at a speed of 402 m/min, but at the cutting depth of 3 mm, the area homogeneous texture fibers was smaller, as shown in Fig. 5

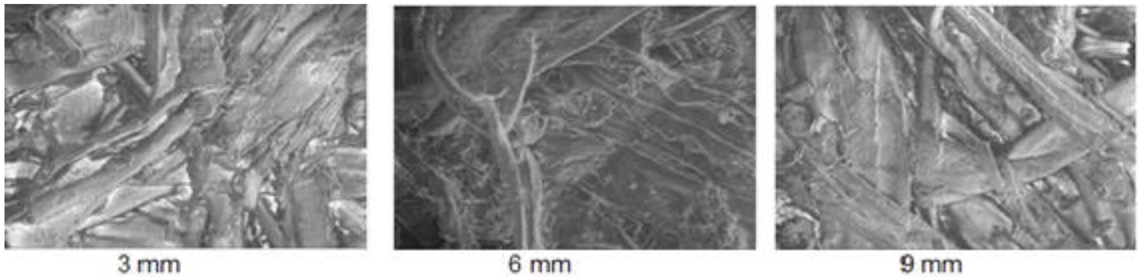

Fig. 5. Cutting depth of 3, 6, and 9 mm for the cutting speed of 402 m/min

At lower cutting speeds, the fibers became damaged and fragmented. Compacted fibers with more homogeneous texture were observed at higher cutting speeds. Results showed that the fibers were less damaged with high speeds and 3 mm depth. The most satisfactory result, according to the SEM image in MDF front milling, occurred with a cutting speed of 1608 m/min, feed rate of 10 m/min, and depth of 5 mm (Davim *et al.* *2*009). Figure 5 shows that the fibers displayed little damage under those conditions.

When comparing the depths 3 mm, 6 mm and 9 mm, it is noted that the depth 9 mm shows more regions of fractured fibers, which appear rough. At 3 mm depth, Fig 5 shows that the changes in the cutting speed present minimal differences. The analyzes of the SEM images are compatible with the results of the R_a Statistic.

Thus, it is to be thought that in frontal milling there is greater destruction of the fibers in the fibrous bonding of the MDF without allowing this to interfere with the surface finish. With the whole fibers, the rugosimeter would have to contour one by one thus raising the value of the roughness.

CONCLUSIONS

1. In frontal milling the differences of the average roughness in the cutting speeds reach 83%, always with satisfactory results in 603 and 804 m/min.
2. In frontal milling, the smaller roughness occurred in the machining depth of 3 mm.
3. The analyzes of the SEM images are compatible with the results of the R_a Roughness statistic.

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