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The quality of MDF workpieces machined in CNC milling machine in cutting speeds, feedrate, and depth of cut

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Abstract Medium density fiberboard (MDF) is an industrial product created from lignocellulosic fibers and resin through the combined action of pressure and heat. Have homogeneity, dimensional stability and mechanical strength similar to solid wood. Milling is a machining method widely used within furniture industries; and despite the noteworthy relevance of the subject, there are few specific works dealing with the MDF milling process using computerized numerical control machines. It is increasingly necessary a programmed machining able to generate suitable surface to coatings, allowing for minimum waste and maximum efficiency, besides the decrease of the tool wear. The irregular surface after machining reduces the quality of the final product; this characteristic is defined by measuring the roughness of MDF panel workpieces. Thus, it is possible to quantify the surface quality and improve the machining process with cutting speed, feed rate, depth cut among others. It was observed that roughness exhibited lower values in higher cutting speeds and low feed rates. The 1 mm depth of cut showed optimized surface results. It was concluded that the parameters studied here significantly influence the finishing, resulting in irregular surfaces that can reduce the quality of products.

Keywords Roughening · Panels · Wood

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1 Introduction

Medium density fiberboard—MDF is an industrial product made of lignocellulosic fibers and resin through the combined action of pressure and heat. It is quite used in the furniture industry, once it presents homogeneity, dimensional stability and wood strength near to solid wood. It easily receives various types of coatings while maintaining quality, and respond positively to machining processes. These qualities are decisive for the industry based on solid wood, such as furniture industry, construction, partitions, floors, doors and other products.

To be used on these applications, a key processing step is necessary for a final quality product: machining. With technological innovation processes in the wood sector, automatic machines that provide automation produce better surface quality of machined workpieces and increase productivity. Machining is an operation aimed at the generation of size, shape and finishing or a combination of these characteristics in one workpiece producing chip [1].

Milling is a machining method widely used in the furniture industry in operations involving machines like planers, routers, thicknessers. Despite the considerable importance of the topic, there are few works dealing with the specific MDF milling process using computerized numerical control (CNC) machines.

This study aimed to investigate the influence the quality os surface of cutting speed, feed rates, and depth of cut in MDF milling through machining center with CNC using hard metal helical endmill.

2 Milling

It is evident the growth in demand for industrial wood products and therefore it increases the need of technological innovations in order to reach market competitiveness. Among these innovations, machining stands out, because it is the most noticeable change among the mechanical metal processes and the timber industry develops machines that provide process automation, resulting in better surface quality of machined workpieces. In [2] commented that the milling is often used in the manufacturing industry. With technology, progress has been made in the procedure, but still there is room for improvement.

Programmed machining, which is able to generate suitable surface for coatings, is increasingly necessary, allowing for minimum waste and maximum efficiency, besides the reduction of tool wear.

Irregular surfaces after machining reduces the quality of the final product. This characteristic is defined by measuring the roughness of workpieces of MDF panels. Thus, it is possible to measure the surface quality and improve the machining process with adjustments to the cutting speed, feed rate, power, and others.

In milling occur vibrations occasioned because of de vibrations in the workpiece. The cutting speed, feed rate and depth cut influence this variation [3]. The nonlinear interaction between the tool and the workpiece causes stability regions which lead to the jamming up of chip formation and consequently unevenness in the workpiece surface. Thus, the stability of cutting influences directly the quality of surface roughness [4].

A study of ductile workpieces done by Balachandran and Zhao [5] investigated the stability of milling in relation to cutting speed and depth of cut. Predicting this pattern can avoid trepidations and separation, influencing the surface of the materials. It was concluded that the cutting speed and depth of cut parameters present instability areas in different rotations.

High surface quality in machining is very importance, for it can influence the cost of the final product in the industry, especially for high durability materials. So, milling operations are almost indispensable, consuming a great deal of time during processes and it has significant impact on the quality of surface finishing, and cost of the final product [6].

This investigation, as the number of revolutions and the depth of cut is increased, surface roughness decreases showing that the roughness is affected by cutting speed, depth of cut, tool conditions and the workpiece [6].

The industry requires improving on cutting conditions and more machining technological investment in order to reduce losses and increase quality. In the study by Shen et al. [7] the roughness of the machined surfaces showed better results for higher cutting speeds.

In a investigated the machining of bracatinga (*Mimosa scabrella*) for using in the furniture industry and obtained utilization of 92 %, but it was highlighted the importance of knowing the wood during machining for the correct use of the workpiece [8].

In a study with CNC milling with 15 kW spindle power, a maximum spindle speed of 32,000 rpm and a maximum feed rate of 10 m/min. It was observed the influence of cutting speed and feed rate parameters through the MDF surface roughness. The surface roughness decreases with increased cutting speed and it increases with the feed rate. MDF milling shows the advantage in using a high cutting speed [9].

The study of the MDF pattern in CNC milling requires more research in relation to surface finishing. The parameters of cutting speed, feed rate and depth of cut should be observed for better roughness.

3 Materials and methods

The analysis of the cutting speed, feed rate and depth of cut influence in surface quality of the MDF workpieces was conducted for the concordant tangential milling in CNC machining centers and performed by trials in a machining center with CNC by SCM model TECH Z1.

Commercial use MDF by Duratex was used with density of 736.22 kg m^{-3}. The specimens were prepared with dimensions of 300 × 65 × 15 mm for better use during machining. The MDF specimens were machined tangentially in the consistent direction with six replicates, in order to make subsidies for adequate statistical analysis. Assays were performed in the tangential direction with depth of cut of 0.5, 1 and 1.5 mm with rotating in the amounts of 16,000, 12,000, 8000 and 4000 rpm, respectively, with values of cutting speed 201, 402, 603 and 804 m/min. Three feed rates were used 2, 4 and 6 m/min. A total of 216 tests were performed. It was used a "top" type carbide endmill for finishing, with three helix cutting teeth, model HWM-Premium—Upcut Spiral Bit, with a diameter of 16 m by CMT—number code 193.161.11.

Ra (roughness average) parameter was used for measuring the roughness average of the workpieces, obtained with a profilometer by TAYLOR HOBSON, sultronic 25 model, with measuring rod with diamond cone-spherical feeler tip, 2 µm radius.

To analyze the results, the statistical analysis was used, involving analysis of variance and Tukey's test to observe the difference between the treatment averages (Table 2).

4 Results and discussion

The roughness average values listed after the milling process for the depth of 1 mm, with their respective values of roughness (Ra) in relation to the cutting speed and feed rates are organized in Table 1, in which it is represented the F index that indicates significant and non-significant statistical difference, the coefficient of Variation (CV) and the feed rate (f).

Table 1 Roughness parameters

Parameters	
Cut-off	2.5 mm
Measuring length	12.5 mm
Filter	Robust Gaussian
Range (resolution)	300 µm

Using Tukey's test, it was observed that there were no statistical differences between the feed rates ($F_f = 1.47$; p value >5 %), i.e., within the feed rates the MDF milling for these conditions, there were no considerable differences. In relation to the cutting speed and feed rate there were no differences either ($F_{Cs \times f} = 1.93$; p value >5 %). There were significant statistical differences on cutting speeds ($F_{Vc} = 13.34$; p value >5 %), as seen in Table 2.

The results for roughness average (Ra) are shown in Fig. 1, according to the machining in consistent direction and with depth of cut of 1 mm. It is observed that there were no significant statistical differences for feed rate of 2 m/min; the values of surface finishing maintained very close. Feed rate showed no significant statistical differences, but the values for feed rate of 4 and 6 m/min were higher. But for all feed rates, the lowest values for surface roughness occurred at the highest cutting speed of 804 m/min (16,000 rpm).

For a depth of 0.5 mm, the roughness average values presented in Table 3 indicate no statistical differences in the feed rate ($F_f = 0.43$; p value >5 %) and the ratio between cutting speed and feed rate ($F_{Cs \times f} = 2.19$; p value >5 %). But among the cutting speeds there were statistical differences ($F_{Cs} = 13.34$; p value >5 %).

At 0.5 mm depth, there was little variation between treatments, with no significant statistical differences. The feed rate of 2 m/min shows lower values for roughness. The lowest values of surface finishing for all feed rates are in higher feed rates of 603 m/min (12,000 rpm) and 804 m/min (16,000 rpm), as shown in Fig. 2.

The average results of roughness for 1.5 mm depth are presented in Table 3. The feed rate had no significant statistical result ($F_f = 0.08$; p value >5 %), different from the cutting speed ($F_{Cs} = 9.45$; p value >5 %) and from the relation between the velocities ($F_{Cs \times f} = 9.81$; p value >5 %), as shown in Table 4.

It is observed in Fig. 3 the statistical differences in cutting speeds, mainly in feed rates of 2 and 6 m/min. It is also observed that there was no significant statistical difference in feed rate for cutting speed of 402 m/min (8000 rpm) and 603 m/min (12,000 rpm). In 1.5 mm depth, it is necessary to consider that there is greater variation in the surface quality of the MDF workpieces.

In machining *Coffea arabica* [9] noted that the corresponding feed tooth values to 0.3–0.8 mm resulted in the quality of fine workmanship. The results showed that the quality of the machined surface

Table 2 Tukey's test for roughness results between different feed rates and different rotations for depth of cut of 1 mm

Tukey for roughness (μm)				
f (m/min)	201 m/min 4000 rpm	402 m/min 8000 rpm	603 m/min 12,000 rpm	804 m/min 16,000 rpm
2	19.1a	17.03a	16.66a	15.83A
4	23.13a	19.16ab	14.93b	14.93B
6	20a	15.11b	15.11ab	14.76B
$F_{(f)}$	1.47 NS			
$F_{(RPM)}$	13.34**			
$F_{(f \times RPM)}$	1.93 NS			
CV	16.38 %			

The letters refer to statistics, when they are equal and no significant difference when different exhibit statistically significant differences

NS non-significant (over 0.05)

* Significant (under 0.05)

** Significant (under 0.01)

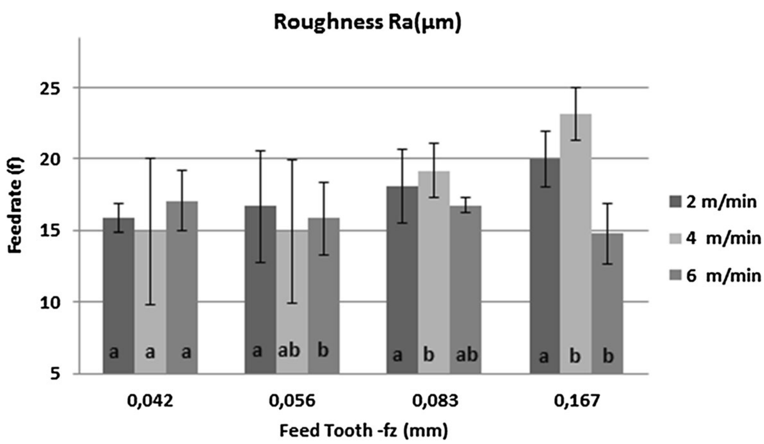


Fig. 1 Roughness for tests with 1 mm depth of cut in consistent direction. The letters refer to statistics, when they are equal and no significant difference when different exhibit statistically significant differences

Table 3 Tukey's test for roughness results between the different feedrates and different rotations for 0.5 mm depth of cut

Tukey for roughness (μm)				
f (m/min)	201 m/min 4000 rpm	402 m/min 8000 rpm	603 m/min 12,000 rpm	804 m/min 16,000 rpm
2	16.07ab	19.1a	13.25b	15.9ab
4	20.12a	15.05a	16.45a	16.3a
6	19a	18.46a	16.75a	13.55a
$F_{(f)}$	0.43 NS			
$F_{(RPM)}$	3.26*			
$F_{(f \times RPM)}$	2.19 NS			
CV	17.57 %			

The letters refer to statistics, when they are equal and no significant difference when different exhibit statistically significant differences

NS non-significant (over 0.05)

* Significant (under 0.05)

** Significant (under 0.01)

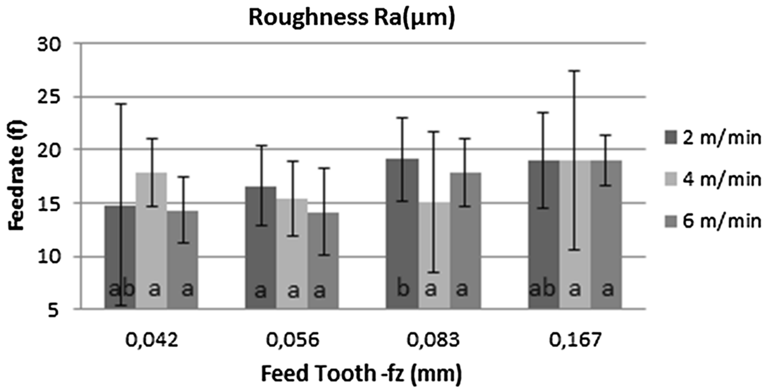


Fig. 2 Roughness for testing with 0.5 mm depth of cut in consistent direction. The letters refer to statistics, when they are equal and no significant difference when different exhibit statistically significant differences

Table 4 Tukey's test for roughness results between the different feed rates and different rotations for 1.5 mm depth of cut

Tukey for roughness (µm)				
f (m/min)	201 m/min 4000 rpm	402 m/min 8000 rpm	603 m/min 12,000 rpm	804 m/min 16,000 rpm
2	20.13aA	17.06bA	14.2cA	13.13cB
4	14.73aB	17.2aA	16.13aA	16.46aA
6	16.46abB	17.06aA	14.06bA	16.73aA
$F_{(f)}$	0.008 NS			
$F_{(RPM)}$	9.45**			
$F_{(f \times RPM)}$	9.81**			
CV	7.13 %			

The letters refer to statistics, when they are equal and no significant difference when different exhibit statistically significant differences

NS non-significant (over 0.05)

* Significant (under 0.05)

** Significant (under 0.01)

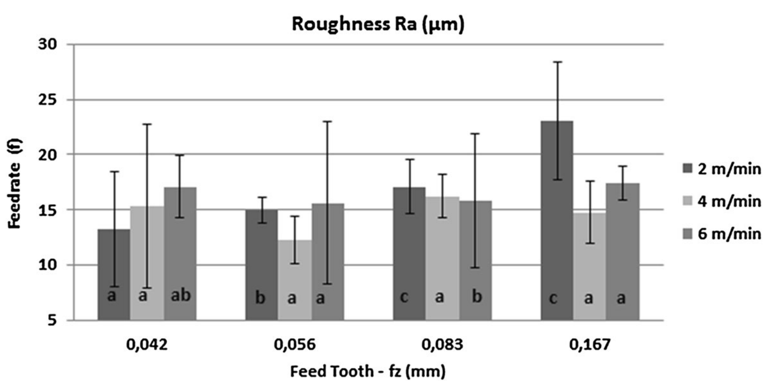


Fig. 3 Roughness for testing with 1.5 mm depth of cut in consistent direction. The letters refer to statistics, when they are equal and no significant difference when different exhibit statistically significant differences

at a feed speed of 6 m/min was satisfactory with small fibers surveys and lower feed per tooth (fz) and surface roughness (Ra).

In a study of machining MDF was observed that the feed per tooth showed a lower rate of advancement and higher rotation showed better results in terms of surface quality. The roughness increases with the growth of feed per tooth [10].

When analyzing the results, it is evident the trend of lower values of roughness average (Ra) occur at higher cutting speeds for all depths. The smaller roughness values occur in cutting speed of 603 m/min (12,000 rpm) and 804 m/min (16,000 rpm); these results are equivalent to [11]. It was investigated the MDF machined surfaces through milling and it was pointed out that lower roughness is related to 904, 5 m/min (18,000 rpm) and 527.6 m/min (10,500 rpm) for 5 mm depth of cut tests. In a wood investigation, the satisfactory results of cutting speed were between 1131 and 1234 m/min [9]. The roughness surface in [6] had rotation of 3000 until 5000 rpm in depth cut of 0.1 until 3 mm. In 5000 rpm, it was observed the smaller roughness values were similar in smaller depth of cut.

High depth of cut values cause high load upon the tool, and consequently, more vibrations and rough regions in the workpiece.

Rossi et al. [12] observed in milling with metals that the parameter depth of cut has little influence in roughness, as well as Castro and Gonçalves [10] that found satisfactory surface roughness in MDF milling with 3 mm value.

In work as measured the surface roughness of clusters and concluded that the surface quality has suffered more influences by the feed per tooth than in cutting speed and depth of cut [13].

Thus, the results of this study proved to be consistent with the literature. The lowest values of surface roughness are found in cutting speed 603 m/min (12,000 rpm) and 804 m/min (16,000 rpm).

With high values of cutting speed each cutter tooth removes less material, causing less vibration and during the same conditions of feed rate provides less rough surfaces.

Because it is MDF material that has packed fibers in its constitution, the discontinuous chip formation causes a surface roughness, so high speed has results that are more satisfactory.

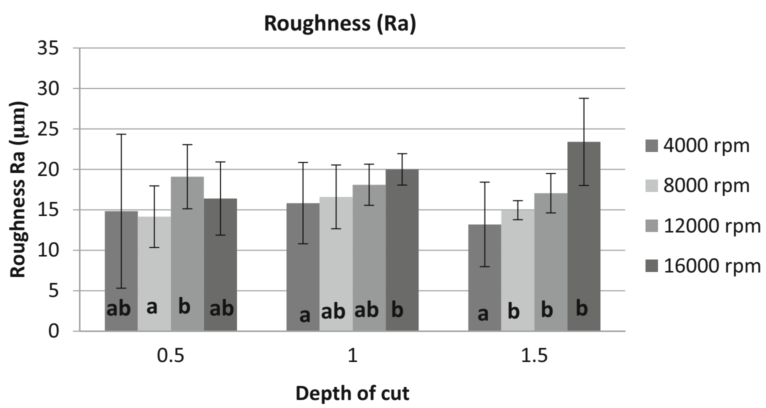


Fig. 4 Roughness of different depths of cut for the feed rate of 2 m/min in consistent direction. The letters refer to statistics, when they are equal and no significant difference when different exhibit statistically significant differences

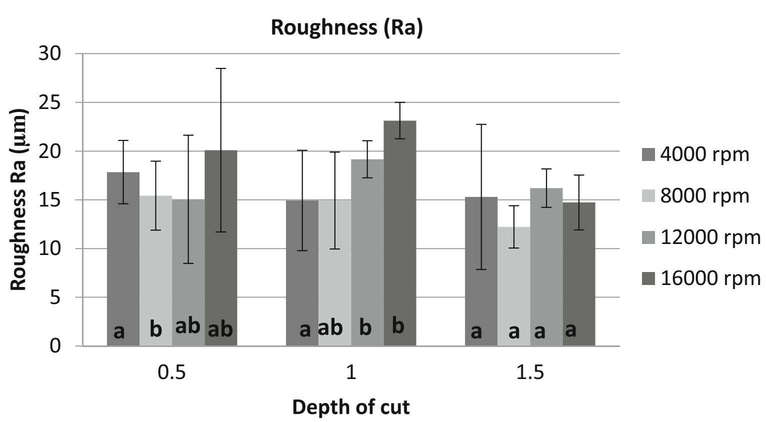
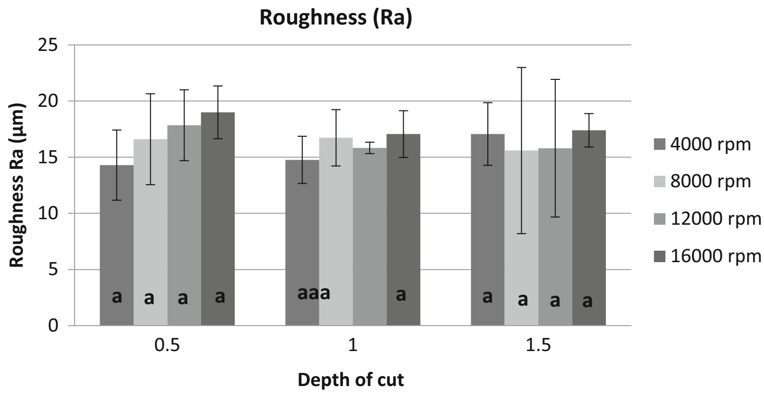


Fig. 5 Roughness of different depths of cut (ap) for the feedrate of 4 m/min in consistent direction. The letters refer to statistics, when they are equal and no significant difference when different exhibit statistically significant differences

Fig. 6 Roughness of different depths of cut (ap) for the feedrate of 6 m/min in consistent direction. The letters refer to statistics, when they are equal and no significant difference when different exhibit statistically significant differences



The surface roughness (Ra) in the depth of cut of 0.5, 1 and 1.5 mm for the feed rate of 2 m/min are seen in Fig. 4.

Significant statistical differences occur between the cutting speeds in 3 depths (ap). For 0.5, 1 and 1.5 mm smaller roughness values occur at lower rotations at 4000 and 8000 rpm (201 and 402 m/min respectively). The roughness pattern on 1 and 1.5 mm depths follows an increasing sequence as the cutting speed is increased. As for the smaller depth, it has unstable pattern in relation to the rotations increase.

The roughness average for the feed rate of 4 m/min at the three depths of cut is illustrated in Fig. 5.

It is observed that there are significant statistical differences in 0.5 and 1 mm depth. A significant trend for lower values of roughness does not occur in these depths. As for the 1.5 mm depth, the lowest values of surface roughness occur.

The roughness average for the feed rate of 4 m/min at the three depths of cut is illustrated in Fig. 6.

It is observed that no significant statistical differences occur for all depths in 6 m/min feed rate.

The roughness in different feedrates shows a tendency to decrease at higher rotations, except in 6 m/min feedrate and 1.5 mm depth of cut. It occurs because the roughness surface has satisfactory quality in high cutting speed and low feedrate as [14] that performed a literature study to evaluate the cutting parameters that influence the final finishing on the wood. Savas et al. [15] investigated roughness surface in tangential milling process and found satisfactory results in 3.2 m/min feedrate. In the same way, Davim et al. [11] concluded that lower roughness occur in 0.5 and 2.75 m/min feedrate.

The 2 m/min feedrate is lower compared with the results in [10], which represented 2.90 m/min. As well as Castro and Gonçalves [10] who reported 3.2 m/min feedrate and 804 m/min (16,000 rpm) cutting speed.

There is a tendency of the lowest values of roughness is related to lower cutting speeds; however it does not occur at 0.5 mm depth of cut with feed rate of 2 m/min and 1.5 mm depth of cut with feed rate of 4 m/min.

High values of cutting speed provide greater material removal by the cutter teeth. Thus, high cutting speed and low depth of cut result in efficient cutting. The feed rate should have low values for efficient performance in finishing, once it reduces stress on the tool, preventing grooves on the surface of the wood.

5 Conclusion

The quality of the surface observed through the MDF milling in CNC, at the conditions mentioned in this study, showed that the appropriate feed rate is 2 m/min along with high values of cutting speed 402 m/min (12,000 rpm) and 201 m/min (16,000 rpm). The depth of cuts showed significant stability in values 1 mm and 1.5 mm.

It is observed that at higher cutting speeds, the roughness average values decrease. The depth of cut and feed rate demonstrate a proportional relationship.

The roughness pattern at different feed rate shows a tendency to decrease with increased cutting speed. With increasing feed rate, the roughness values decrease.

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