Proceedings of the 51st International Convention of Society of Wood Science and Technology
November 10-12, 2008 Concepción, CHILE

ROUGHNESS PROFILE AND CUTTING ENERGY IN MDF RIP SAWING

PERFIL DE RUGOSIDAD Y ENERGÍA DE CORTE EN EL PROCESAMIENTO DE MDF CON SIERRA CIRCULAR

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ABSTRACT

Materials like medium density fiberboards (MDF) are characterized by a profile of density, with external layers heavier than the core. These differences generate a variable surface quality. Concerning the cutting energy, there are important variations when machining conditions are modified, or when some tool characteristics are changed.

The aim of this research is to evaluate and quantify the cutting energy required to rip sawing MDF and to study the relationship with the resulting surface roughness across the profile when the material density changes.

The finding lead to conclude a close relationship between cutting energy and surface roughness, being particularly sensitive to changes in density within the profile of the board, and in particular to changing cutting conditions expressed as mean chip thickness.

Keywords: Circular saw, roughness profile, MDF, cutting energy.

RESUMEN

Los tableros de densidad media (MDF) se caracterizan por un perfil de densidad que presenta capas exteriores más densas respecto del centro del tablero. Estas diferencias de densidad generan como resultado del maquinado una calidad superficial variable. En relación a los requerimientos de energía de corte, se pueden observar variaciones importantes cuando las condiciones de corte son modificadas, o cuando algunas características de las herramientas de corte cambian.

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El objetivo de este estudio es evaluar y cuantificar la energía de corte requerida durante el corte longitudinal de MDF utilizando sierras circulares, y estudiar la relación con la rugosidad superficial resultante dentro del perfil cuando varía la densidad.

Los resultados encontrados permiten concluir que existe una relación estrecha entre la energía de corte y la rugosidad superficial resultante del proceso de corte, siendo particularmente sensible a la variación de densidad dentro del perfil del tablero, y en particular al cambio de las condiciones de corte expresado como espesor medio de viruta.

Palabras clave: Sierra circular, perfil de rugosidad, MDF, energía de corte.

INTRODUCTION

The resulting surface roughness in wood machining is influenced by cutting conditions, namely by the change in the mean chip thickness (Kivimaa. 1950), but also for the cutting geometry, and tool wear. In wood machining process, the wood species, his anatomical structure, wood density and moisture content, are important variables on the outcome as well.

Medium density fiberboards (MDF) are wood based panels which feature a homogeneous constituent elements, characterized because in its manufacturing process, the resulting density profile across the board present a high density outer layers and a low density core. These differences in the density profile generate as a result of machining a variable surface quality. In this sense Aguilera et al. (2000) and Akbulut & Ayrilmis (2006) have reported variations in surface roughness at different machining conditions or at manufacturing for these boards, delivering the first author reports of board density profile relationship with the resulting surface roughness, as well as the effect of changing cutting conditions on surface roughness and cutting power.

With regard to the cutting power requirements, it is possible to detect variations if the machining conditions are modified, affecting the resulting surface quality (Aguilera et al. 2007, Murase 1994, Tanaka 1991, Zhao et al. 1991) or when some tooling characteristics change, such as the number of teeth or type of machining process (Kilic et al. 2006), being possible to estimate the resulting surface roughness through measurements of cutting power.

There is not enough background about cutting power requirements in MDF rip sawing and its relationship to cutting quality, records that would establish what kind of cutting tool would be more efficient in processing this material.

The aim of this study is to monitor the cutting energy required in longitudinal direction, for medium density fiberboards of three different thicknesses, using circular saws, and study the relationship with the resulting surface roughness within the profile when the density varies.

MATERIAL AND METHODS

The material under study corresponds to MDF light commercial-type format 1.52 x 2.44 m. The main features of this product show an average density of 620 kg/m^3 with a tolerance of ± 25 kg/m^3, and moisture content between 5 and 11%.

From this type of material, panels were selected from three thicknesses 9, 15 and 18 mm (Note: the actual values are: 9.6, 15.2 and 18.2 mm). From each board, samples were extracted randomly for moisture content and density determinations, according to procedures outlined in Chilean Standard NCh176/1 and NCh176/2 respectively.

The samples were machined in a single-spindle shaper machine with variable cutting speed and feed. Two circular saws were involved in the tests, both with tungsten carbide (HW) teeth, with common features as cutting diameter of 200 mm and 3.2 mm kerf. The differences are in the number of teeth, and their linear and geometric parameters, which are shown in the table below.

Table 1 Linear and geometrical parameters of studied circular saws.

Parameter	**Saw A**	**Saw B**
Number of teeth	34	24
Tooth pitch	18.48 mm	26.18 mm
Tooth height	10.70 mm	15.00 mm
Rake angle	20º	20º
Sharpness Angle	50º	55º
Clearance angle	20º	15º

To measure the cutting energy it was utilized a piezo – electrical element connected to a SEK 3243 computer card to record acoustic emissions signals broadcast a continuous channel with a frequency response exceeding 1 MHz. The surface roughness was measured with a contact stylus Mitutoyo Sj-201.

A factorial experimental design was established (Table 2) with one level to rotation speed, four levels for feed speed, three levels for cutting height given by the board thickness, and two types of circular saw, whose main difference is the number of teeth, is therefore deemed a total of 10 repetitions for each machining situation in cutting energy measurements, namely the total number of cuts was 120 by saw type, analyzing the surface roughness in 50% of the samples. It was then determined as variables to study the chip thickness, number of teeth (Z), and the density profile of the panels. The response variables are the cutting energy and surface roughness. The roughness parameter "Rz" average heights pick-valley (ISO 4287 1997), was considered to assess the surface characteristics of the samples.

Table 2 Experimental design for the two circular saws involved in the study

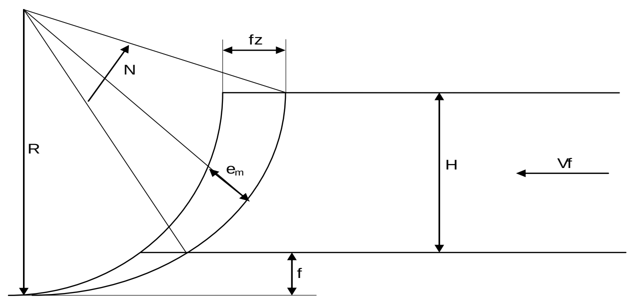
Rotation speed (rpm)	Feed speed (m/min)	Board thick (mm)	Saw A (Nº teeth)	Saw B (Nº teeth)
4250	4.2	9.6	34	24

4250	8.4	9.6	34	24
4250	10.8	9.6	34	24
4250	21.5	9.6	34	24
4250	4.2	15.2	34	24
4250	8.4	15.2	34	24
4250	10.8	15.2	34	24
4250	21.5	15.2	34	24
4250	4.2	18.2	34	24
4250	8.4	18.2	34	24
4250	10.8	18.2	34	24
4250	21.5	18.2	34	24

The average chip thickness in orthogonal cut and parallel to the fiber for circular trajectory is defined according to Juan (1992) as follows:

$$e_m = \frac{1000 * Vf}{N * Z * D} * \left(\sqrt{(D - H - f) * f} + \sqrt{(D - f)(H + f)} \right) \quad (1)$$

Where:
e_m = mean chip thickness (mm)
f = override (mm)
N = rotation speed (rpm)
D = tool diameter (mm) (2*R)
H = cutting height (mm)
Vf = feed speed (m/min)
Z = number of teeth



The samples were random extracted from each class of board in a variable number, which dimensions are 400 mm in length and 120 mm wide. Through machining test, at every sample were monitored the cutting energy, generating then a remaining piece of which was measured the surface roughness (Figure 1) in three sections of the long and within each section in a variable number in the profile until reach the core (3, 4 and 5 measurements for 9, 15 and 18 mm respectively).

Thus, for a 9 mm board, 5 samples were subjected to roughness measurement, into three sections and three layers each (external, middle and interior), then giving a total of 45 measurements (15 data per layer). Similar case to 15 mm board but considering the measurement into four layers (external, middle 1, middle 2 and interior), giving a total of 60 data 5x3x4 = (15 data per layer) and finally for 18 mm, five layers (external, middle 1, middle 2, middle 3 and interior), 5x3x5 = 75 data.

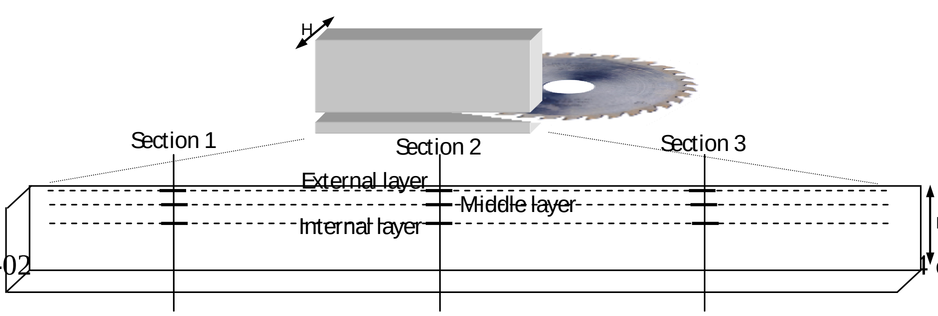


Figure 1 Outline for measuring surface roughness on 9 mm thick board.

A series of 4 pieces was extracted by each board for moisture content determination, which remained in oven until constant weight and by difference with wet weight determines the percentage of moisture. For density determinations, it was considered at current moisture content. The procedure consisted of sectioning samples at layers of 1 mm thick, starting from the surface to reach the core of the board. For difference in weight and volume were able to determine the average density profile for each board.

RESULTS

The resulting moisture content ranged from 9.3% for 9 and 15 mm thick, to 8% for 18 mm thick board. Fiberboards densities were 640 kg/m^3 for 9 mm thick board, 593 kg/m^3 for 15 mm and 632 kg/m^3 for 18 mm.

Figure 2 presents the MDF's density profile, resulting in a very high density in the outer layer of all boards, reaching values of 0.9 g/cm^3 (at 8 to 9% moisture content), and then descend to reaches the core of the board with 0.6 g/cm^3 for the case of 9 mm and 0,48 g/cm^3 for 18 mm board. The detected profiles are similar for the three thicknesses studied, being lower the density for 15 mm board.

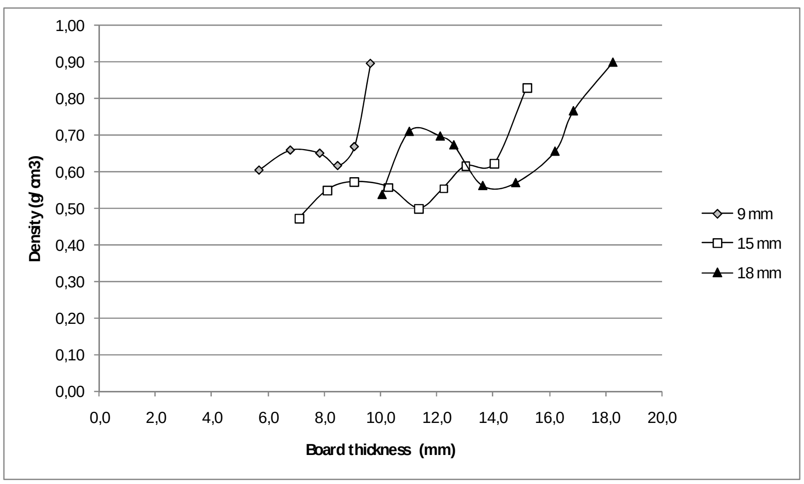


Figure 2 Density profile for studied boards

Analyzing the surface roughness by feed speed, it was found a better quality with Z34, and as expected, a continuing deterioration of the machined surface with the increase feed speed (figure 3).

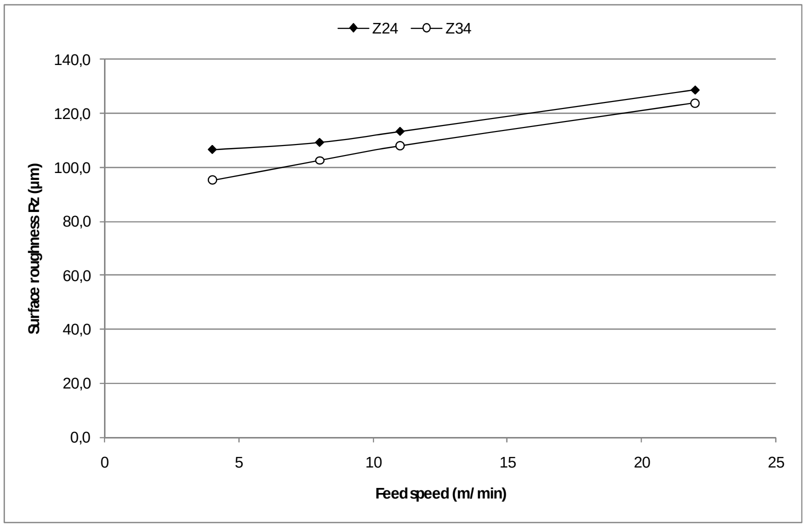


Figure 3 Surface roughness behaviors by feed speed for both saws

The behavior of surface roughness (Rz) by density of the board are presented in the following figures (figure 4, 5 and 6) for both saws (Z34 and Z24), considering the average roughness for density layer (outer layer, middle 1-2-3 when appropriate, and inner layer).

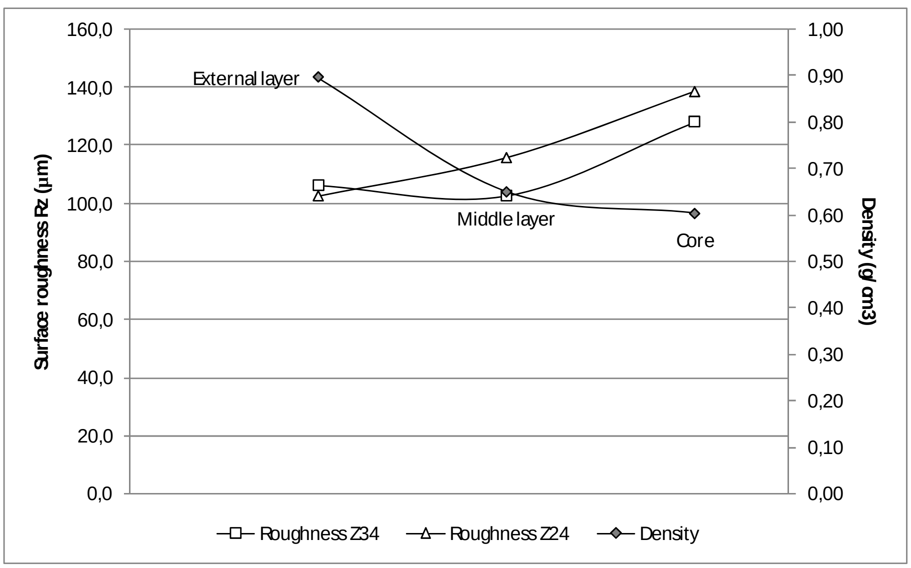


Figure 4 Surface roughness in 9 mm board by saw and density layer

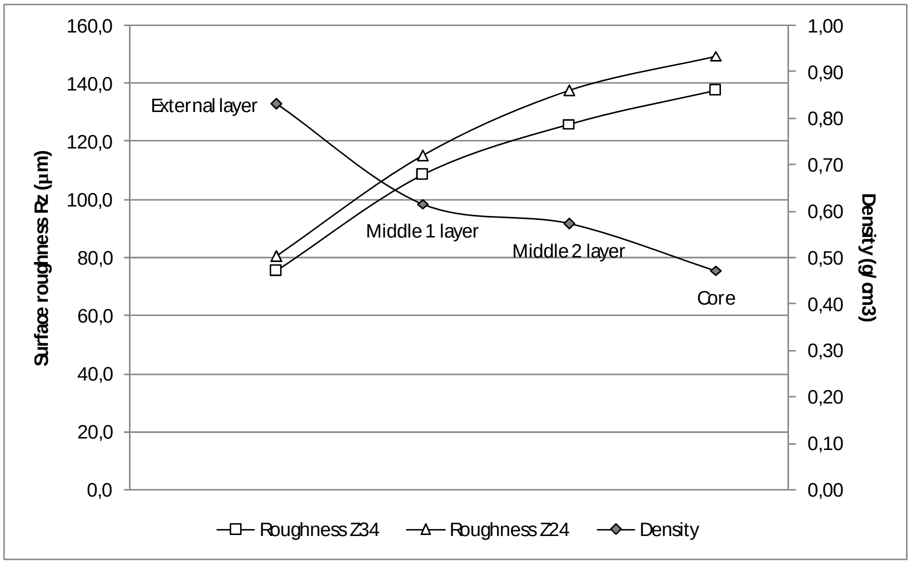


Figure 5 Surface roughness in 15 mm board by saw and density layer

In these figures, it is possible to observe the relationship between MDF density profiles and resulting surface roughness, namely the outer layers were higher density with a surface roughness of lesser magnitude, and the core of the board of lesser density with the highest values of roughness.

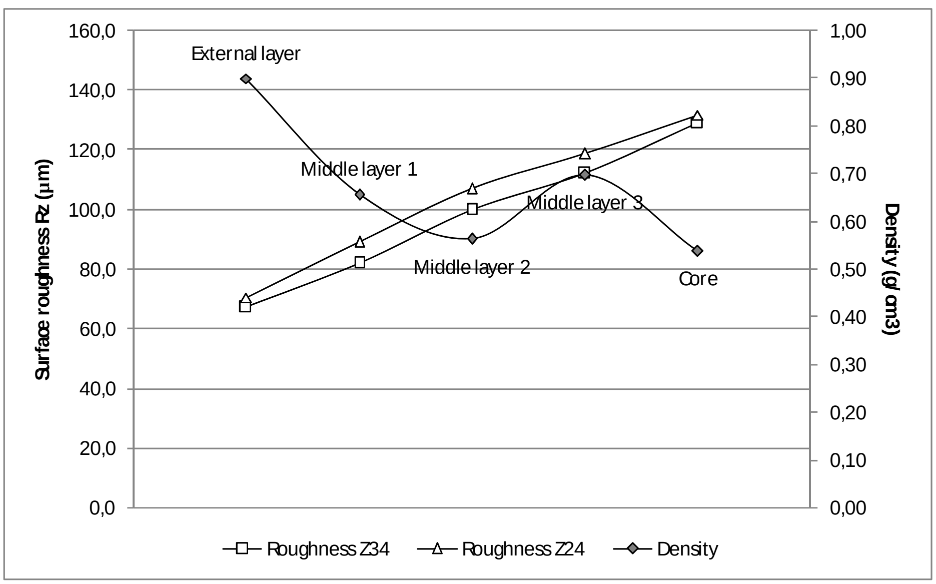


Figure 6 Surface roughness in 18 mm board by saw and density layer

In relation to the saw type, both shows a similar trend, being the 24 teeth saw which generate a rougher surface. A comparison between boards, the three reached similar values of surface roughness at the core, however, for the outer layers, is on the board of 18 mm thick where lower values of surface roughness were observed, following the board of 15 mm. The results of analysis of variance indicate no significant differences between the two saws for surface roughness, nor among the boards.

The results of the measurements of cutting energy are presented in relation with average chip thickness according to equation (1), and under the cutting conditions indicated in table 2, the resulting mean chip thickness are indicated in the table below:

Table 3 Mean chip thickness for the saws in study

Rotation speed (rpm)	Feed speed (m/min)	Cut height (mm)	Mean chip thickness (mm) Saw Z 34	Mean chip thickness (mm) Saw Z 24
4250	4.2	9.6	0.0128	0.0182
4250	8.4	9.6	0.0257	0.0363
4250	10.8	9.6	0.0330	0.0467
4250	21.5	9.6	0.0657	0.0930
4250	4.2	15.2	0.0141	0.0199
4250	8.4	15.2	0.0282	0.0399
4250	10.8	15.2	0.0362	0.0513
4250	21.5	15.2	0.0721	0.1021
4250	4.2	18.2	0.0147	0.0208
4250	8.4	18.2	0.0294	0.0416
4250	10.8	18.2	0.0377	0.0535
4250	21.5	18.2	0.0751	0.1064

Note: Saw diameters (D) 200 mm, override (f) 6 mm, the cutting height match with board thickness.

It is noted in figures 7 to 9 a lower level of cutting energy for 34 teeth saw over 24 teeth saw (statistically significant difference), besides being lower the cutting energy requirements for 9 mm over 15 mm board thick and erratic behavior for 18 mm board.

One aspect that is evident is the increase of the cutting energy when the mean chip thickness decrease, a finding consistent with what was observed by Kivimaa (1950) in the sense that the author indicates an abrupt increases in the curve of cutting energy when the values of the mean chip thickness were lower than 0.05 mm.

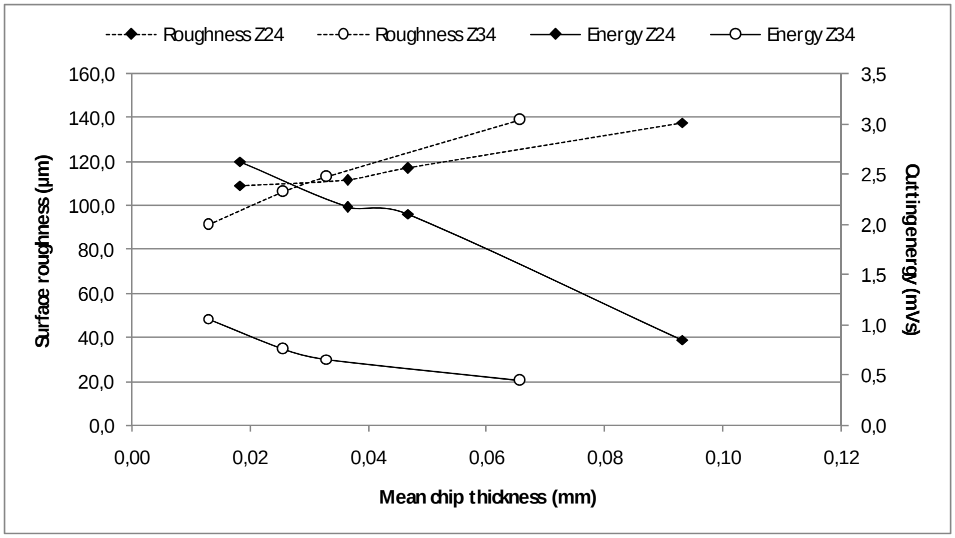


Figure 7 Relationship between surface roughness (Rz) – cutting energy depending on mean chip thickness and type of saw for 9 mm board

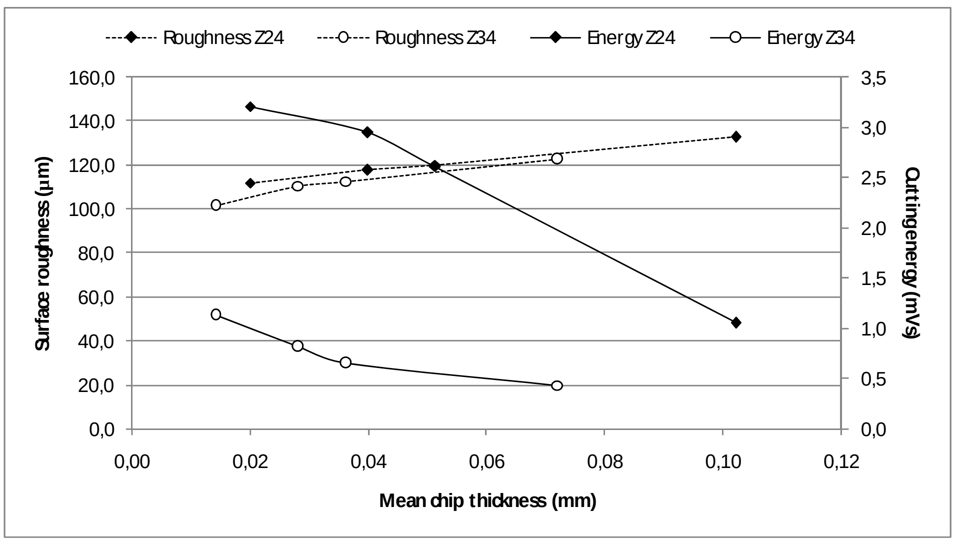


Figure 8 Relationship between surface roughness (Rz) – cutting energy depending on mean chip thickness and type of saw for 15 mm board

This result also indicates the importance of the mean chip thickness as a primary factor that influences the character of the whole machining process, significantly affecting the cutting energy and secondly to the surface quality resulting from the process. In the latter, these figures show the dependence of the roughness on the level of chip thickness, which increase reflects a deterioration of the surface.

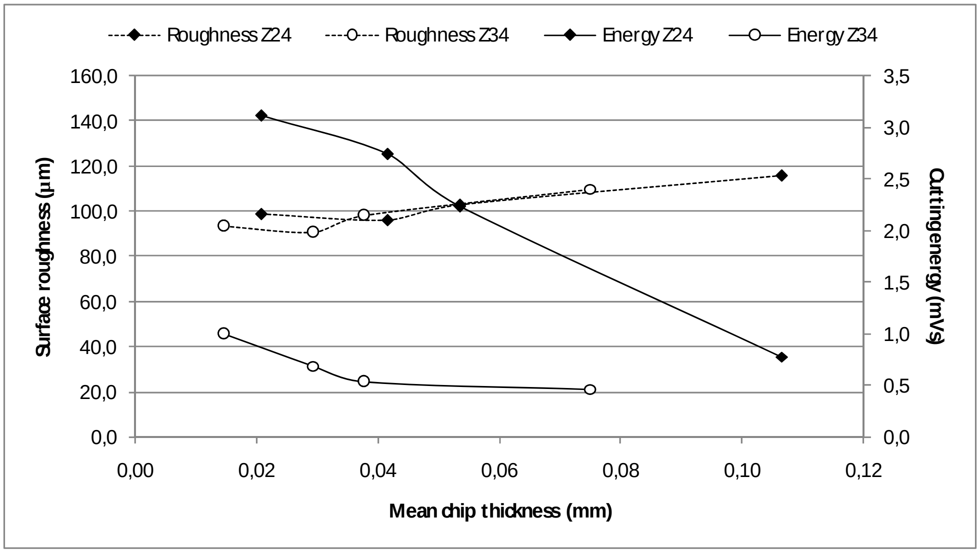


Figure 9 Relationship between surface roughness (Rz) – cutting energy depending on mean chip thickness and type of saw for 18 mm board

Is therefore with thinner chips, where it is possible to obtain a better surface quality, however, with a higher level of cutting energy. Resulting surface roughness generated for both saws it was homogeneous, following the same trend and reaching high levels when the mean chip thickness is generated at a feed speed of 22 m/min. It is at this speed where the type of saw loses importance, because the machining quality is poor on the roughness obtained.

CONCLUSIONS

The density profile of MDF responded very well to cutting conditions change, which showed an increase in roughness with the decline in density at the core of the board, being also accentuated the effect when a fewer teeth saw was used. During the cutting process, the circular saw generated a very small level of chip thickness (micro-chips), which showed a behavior consistent with both cutting energy as well to the surface roughness. Being very small chips, the cutting energy presented an upward trend when it lowered the mean chip thickness, being in conjunction a decrease on surface roughness with the decline in the chip thickness.

The cutting energy was sensitive to the change of machining conditions, in particular with the change of saw type, requiring more cutting energy with fewer teeth, but deteriorating more the surface, showing the same trends for all boards studied. Finally, using circular saws in MDF processing, a high feed speed produces more worsen finish surface over the board edge, demanding in the process a lower cutting energy, independent of the thickness of the board.

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Acknowledgments
The execution of the trials, data collection and sample preparation was supported by Mr. Eder PARDO, without whose cooperation, this study would not have been possible; the author therefore expresses its most sincere thanks. Also appreciates the cooperation of the Dirección de Investigación of the Universidad Austral de Chile.