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EFFECT OF MACHINING PARAMETERS ON SURFACE QUALITY AFTER FACE MILLING OF MDF

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ABSTRACT

Medium density fibreboard (MDF) is an engineered wood product which is preferred to solid wood and other wood based composites in many applications due to certain comparative advantages especially in furniture manufacturing. Face milling is the machining operation frequently used in engraving parts of MDF and in furniture manufacture. This study focused on machining parameters which are related the surface roughness of the pocket milled MDF routed by a CNC machine. The effects of the spindle speed, feed rate, stepover and depth of cut were investigated on the surface roughness of the MDF panels. Surface parameters used to evaluate surface quality in this study are roughness average (Ra), mean peak-to-valley height (Rz) and Root-mean-square (Rq). The results demonstrated that the surface roughness decreases with increasing spindle speed and increases with increasing stepover, feed rate and depth of cut. The milling tests showed the important role spindle speed plays on the evolution of the surface roughness as a function of material removal rate (MRR). The effect of factors on surface roughness has been illustrated.

KEYWORDS: Groove milling, medium density fibreboard, surface roughness, wood machining.

INTRODUCTION

For many of the world's population, the growing integration of the global economy has provided the opportunity for substantial income growth. This is reflected not only in higher incomes, but also in the improved availability of better quality and increasingly differentiated final products (Kaplinsky and Readman 2005). For that reason, many companies in the furniture and joinery industry actually use Computer Numerical Control (CNC) machines in their production. Thus, creating brand awareness with local identity in furniture production can be available.

Machining parameter related the surface roughness of pocket milled MDF material by using CNC router affects surface properties of the MDF panels. The CNC routers were first used by the aerospace industry to cut complex patterns out of sheets of aluminium. Then, by the early 80's, this technology was used in many types of machinery in the secondary woodworking industry. New functionality and improved performance has being developed day by day which have given CNC an ever increasing role in the success of wood machining sector (Albert 2009). CNC has been widely introduced in wood industries for automatically cutting, drilling, and shaping. A type of CNC router has become especially popular in furniture manufacturing, and has been used for the grooving, side milling, and patterning of furniture material and this technology presents many advantages related to output, surface quality and provide greater improvements in productivity, and increase the quality of the machined part (Costes and Larricq 2002, Ohuchi and Murase 2006)

Among several CNC industrial machining processes, milling is a fundamental machining operation (Lou et al. 1998). This operation has frequently used in furniture manufacturing. While the side milling has been studied extensively in the literature, grooving and its effect on surface quality on grooved surface have not received much attention. In this process, proper setting of cutting parameter is important to obtain better surface roughness (Rashid and Abdul Lani 2010).

MDF made out of wood fibres glued together with resin by heat and pressure is an industrial wood product. Due to its better machinability, dimensional stability and surface characteristics, MDF is appropriate for many interior and exterior construction and industrial applications, especially, in the furniture industry (Davim et al. 2008). However, MDF is a far more homogeneous wood based material than solid wood and it has smoother surface than that of any other wood composite panels such as particleboard. Therefore, it is widely used as substrate for thin overlays such as resin-impregnated papers, other decorative overlays and direct finish to the surface for different uses including door skin. The surface roughness of the panel plays an important role since any surface irregularities may show through thin overlays reducing the final quality of the panel (Hiziroglu and Kosonkorn 2006).

The surface roughness of wood products and MDF are depending on many factors and can be related both to physical properties of panel and machining conditions (Magoss 2008, Stewart 1992, Engin et al. 2000, Philbin and Gordon 2006, Lin et al. 2006). Among the physical properties, the wood species, density, moisture content, fiber mixture, the structural properties and among the machining conditions cutting parameters (feed rate, spindle speed, cutting speed, width and depth of cut) cutting forces, cutting tool are to be mentioned. However, in last decades, many works of various authors, when reporting about the milling of wood based material have shown that the machinability is strongly dependent on the mechanics of cutting, the cutting tool and the work piece material (Boucher et al. 2007).

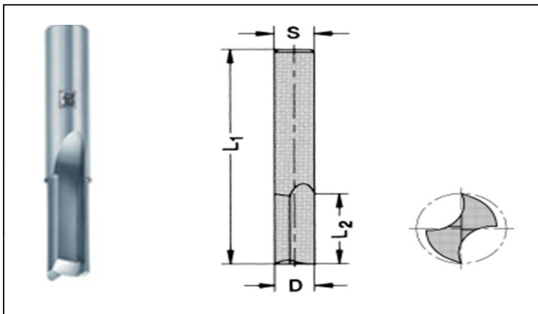
Recently, Davim et al. (2000) investigated the influence of cutting speed and feed rate on surface roughness in MDF milling by CNC router. They evaluated the surface roughness as a function of material removal rate (MRR) for different spindle speed and suggested high spindle speed for reduction of surface roughness.

The objective of the present study is focused on the effect of the cutting parameters, used in pocket milling of MDF, on surface roughness. Selection of cutting speed, feed rate, axial depth of cut and stepover (radial depth of cut) values are all important variables which define surface quality. The effects of every single variable on surface roughness are known, but results revealed in their combinations cannot be clearly estimated.

MATERIAL AND METHODS

Commercially available MDF panels with thickness of 18 mm are used in the experiments. The moisture content (6.6 %) and density (0.736 g.cm^{-3}) of MDF panels were determined according to ISO 3130 (1975) and ISO 3131 (1975), respectively. Moisture content of wood at the time of processing is one of the most important factors affecting surface roughness of the MDF panels. Previous studies showed that surface roughness increase with increasing moisture content. For this reason, it stated that the most appropriate moisture content should be around 6 % (Kurtoğlu 1981).

The experiments were carried out on the MDF panels using router cutter, with 6 mm of diameter. The properties of router tools has presented in Fig. 1. Mekano P 1500 CNC router was used as the milling machine. This machine is equipped with 18 000 rpm spindle, and is capable of machining at feed rates of up to 6 m.min^{-1}.



S=6 mm
L_1=50 mm
D= 6 mm
L_2=14 mm

Fig. 1: Router cutter used on experiments.

In this study; using zigzag cutting path, pocket milling has been employed on MDF by using CNC router. The effects of different values of spindle speed, feed rate, stepover and axial depth of cut on surface roughness was investigated (Fig. 2).

Stepover is a milling parameter that defines the distance between two neighboring passes over the work piece. In this study, stepover was chosen 1 mm and 3 mm (varying from approximately 15 % and 50 % of tool diameter). It is usually given as a percentage (ratio) of the tool diameter and usually called as stepover ratio. Stepover can be define as “radial depth of cut” in this situation. Tab. 1 shows the cutting parameters used for MDF pocket milling tests.

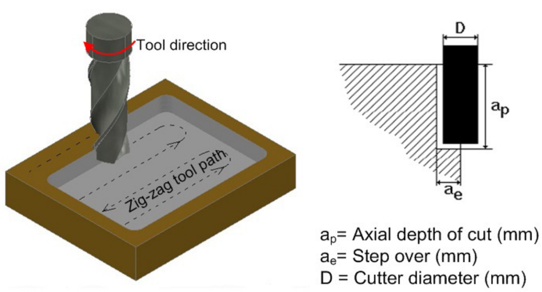


Fig. 2: Parameters of pocket milling surface.

Tab. 1: Cutting parameters.

Factors	Level_1	Level_2	Level_3
Axial depth of cut	2 mm	4 mm	6 mm
Stepover	1 mm	3 mm	-----
Feed rate	0.5 $m.min^{-1}$	2.5 $m.min^{-1}$	5 $m.min^{-1}$
Spindle speed	12 000 rpm	15 000 rpm	18 000 rpm

A total of 54 pieces dimensions of 5 x 5 cm were designed with ArtCAM- Artistic CAD/CAM Software and grooved on MDF panels by CNC router (Fig. 3). Surface roughness was measured across the stepover of the samples with a stylus type profilometer (Mitutoyo SJ-201) which has 8 mm tracing length. From each specimen, five measurements conducted and average values calculated. Three roughness parameters characterized by ISO 4287 (1977) standard, roughness average (Ra), mean roughness depth (Rz) and root mean square roughness (Rq) are the most commonly used parameters in stylus method and were considered to evaluate quantitatively surface characteristics of the specimens. Variance analysis was used with Minitab 15 for the statistical analysis of the Ra, Rz and Rq values obtained.

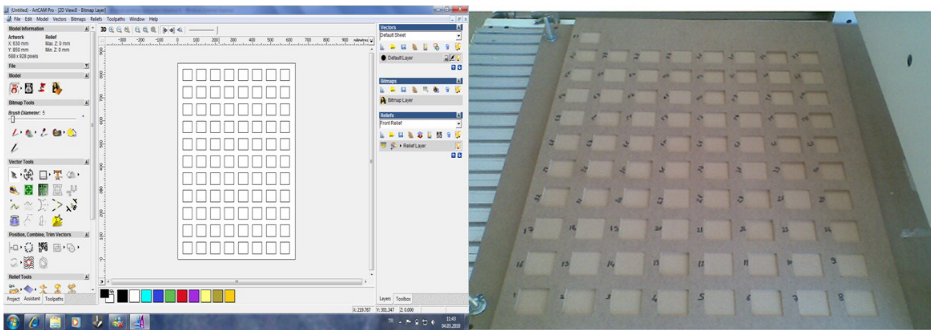


Fig. 3: CAD/CAM design and machined on MDF panels.

RESULTS AND DISCUSSION

The results of the experiment allowed the evaluation of the surface quality of panels as a function of machining parameters. Descriptive statistics for Ra, Rz and Rq are shown Tab. 2.

Tab. 2: Descriptive statistics.

Variable	N	Mean	St.Dev.	Minimum	Maximum
Ra	270	8.485	1.853	4.420	13.980
Rz	270	51.579	10.908	27.540	88.690
Rq	270	10.748	2.338	5.710	17.740

ANOVA tables have been compiled with average surface roughness values obtained from the experiments. The effects of related parameters on surface roughness have been determined. The results of variance analysis are given in Tab. 3. From the analysis, it is easy to identify which factors are important in terms of surface quality. Use the p-values (P) in the Estimated Effects to determine which effects are significant. Using a = 0.05, there is statistically significant effect of all the factors on Rq; that is, their p-values are less than 0.05. But there is no significant effect of dual interactions of stepover* axial depth of cut, stepover* spindle speed on Ra and also, feed rate * axial depth of cut on Rz.

The most common measure of the overall fit of a regression is the coefficient of determination, denoted R^2. This value provides a measure of variability in the observed response values and can be explained by the experimental factors and their interactions. It measures the proportion of the variance in the dependent variable explained by the independent variable. This coefficient is computed using either the variance of the errors of prediction or the variance of the predicted values in relation to the variance of the observed values on the dependent variable. By using statistical software, R^2 values for Ra, Rz, Rq was found 89.19 %, 77.65 %, 71.91 % at a 95 % confidence level, respectively. R^2 can be explained by single, double, triple and quadruple interactions of stepover, feed rate, spindle speed and axial depth of cut.

Fig. 4 shows the single effect of processing parameters on Ra. From Fig. 3 it can be concluded that surface roughness decrease with increasing spindle speed and increase with increasing stepover, feed rate and axial depth of cut. Surface roughness had the lowest value in 18 000 rpm spindle speed, 1 mm stepover, 0.5 m.min^{-1} feed rate and 2 mm depth. Topal (2009) presented that surface roughness values are significantly influenced by stepover. As a mention that; high stepover of rough machining and low stepover of end machining is preferred. The figure also indicates that the axial depth of cut has a considerably effect on the surface roughness. As stated in the literature, due to the difference density between the layers in MDF panels, surface roughness increase with increasing axial depth of cut (Aguilera et al. 2000, Lin et al. 2006, Akbulut and Ayrılmış 2006).

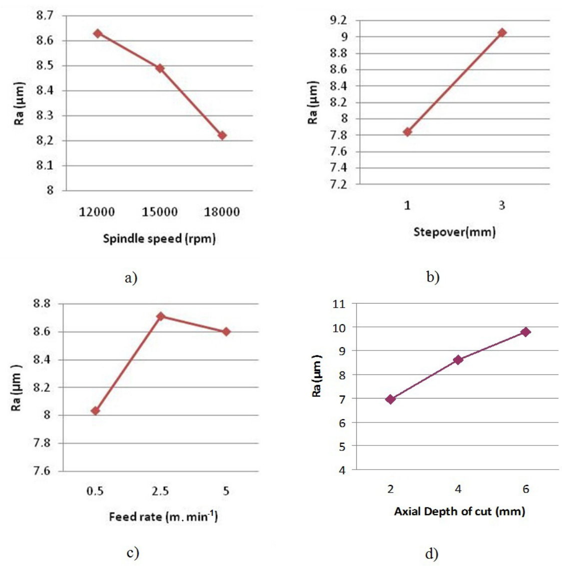


Fig. 4: The effect of processing parameters on surface roughness (Ra).

Tab. 3: The table of variance analysis.

Source	DF			Seq SS			Adj MS			F			($p \leq 0.05$)		
	Ra	Rz	Rq	Ra	Rz	Rq	Ra	Rz	Rq	Ra	Rz	Rq	Ra	Rz	Rq
Stepover	1	1	1	109.214	4137.33	176.613	109.214	4137.33	176.613	236.39	124.94	102.61	0.000	0.000	0.000
Feed rate	2	2	2	16.781	525.05	27.603	8.391	262.53	13.801	18.16	7.93	8.02	0.000	0.000	0.000
Axial depth of cut	2	2	2	369.582	10167	574.559	184.791	5083.49	287.280	399.98	153.52	166.91	0.000	0.000	0.000
Spindle speed	2	2	2	9.574	711.7	14.726	4.787	355.85	7.363	10.36	10.75	4.28	0.000	0.000	0.015
Stepover* feed rate	2	2	2	12.718	526.31	20.456	6.359	263.16	10.228	13.76	7.95	5.94	0.000	0.000	0.003
Stepover* axial depth of cut	2	2		0.129	15.37		0.065	7.69		0.14	0.23		**0.870**	**0.793**	
Stepover* spindle speed	2	2		2.996	51.64		1.498	25.82		3.24	0.78		**0.041**	**0.460**	
Feed rate* axial depth of cut	4	4	4	17.923	206.46	26.819	4.481	51.62	6.705	9.7	1.56	3.90	0.000	**0.186**	0.004
Feed rate * spindle speed	4	4	4	38.084	730.14	59.427	9.521	182.53	14.857	20.61	5.51	8.63	0.000	0.000	0.000
Depth of cut* spindle speed	4	4	4	74.91	2391.97	114.866	18.727	597.99	28.716	40.54	18.06	16.68	0.000	0.000	0.000
Stepover *feed rate * axial depth of cut	4	4		29.723	663.52		7.431	165.88		16.08	5.01		0.000	0.001	
Stepover *feed rate *spindle speed	4	4		19.369	514.49		4.842	128.62		10.48	3.88		0.000	0.005	
Stepover *axial depth of cut *spindle speed	4	4		35.046	1457.66		8.761	364.42		18.96	11.01		0.000	0.000	
Feed rate *axial depth of cut*spindle speed	8	8	8	28.218	643.57	42.626	3.527	80.45	5.328	7.63	2.43	3.19	0.000	0.016	0.002
Stepover *feed rate * axial depth of cut *spindle speed	8	8		59.314	2114.64		7.414	264.33		16.05	7.98		0.000	0.000	
Error	216	216	240	99.792	7152.52	413.071	0.46	33.11	1.721						
Total	269	269	269	923.372	32009.4	1470.77									
	R^2= 89.19 % for Ra							**R^2=77.65 % for Rz**			**R^2=71.91 % for Rq**				

The effect of dual interactions processing parameters on surface roughness are presented in Fig. 5. As showing figure, surface roughness decrease with increasing spindle speed, decreasing feed rate and axial depth of cut.

Material removal rate (MRR) determines the economics of machining and rate of production. In setting the machining parameters, the main goal is the maximum MRR with the optimum surface roughness. The volume of the removed material identifies the volume occupied by a chip with cross section (depth of cut multiplied with feed) and a defined length per minute (Tschätsch 2008). Material removal rate (MRR) is the volume of material removed in unit time. For milling, MRR in $cm^3.min^{-1}$ is given by (Parashar and Mittal 2006):

$$MRR = \frac{a_p a_e v_f}{1000} \quad (cm^3.min^{-1})$$

ap - axial depth of cut (mm) ae - radial depth of cut (mm), vf - feed speed ($mm.min^{-1}$)

In Fig. 6, it can be observed the evolution of the surface roughness as a function of MRR for different spindle speed. The lowest surface roughness was obtained in 18 000 rpm spindle speed and 90 $cm^3.min^{-1}$ MRR. It can be shown that to reach better surface roughness in which higher material removal rate value is only available in high spindle speed.

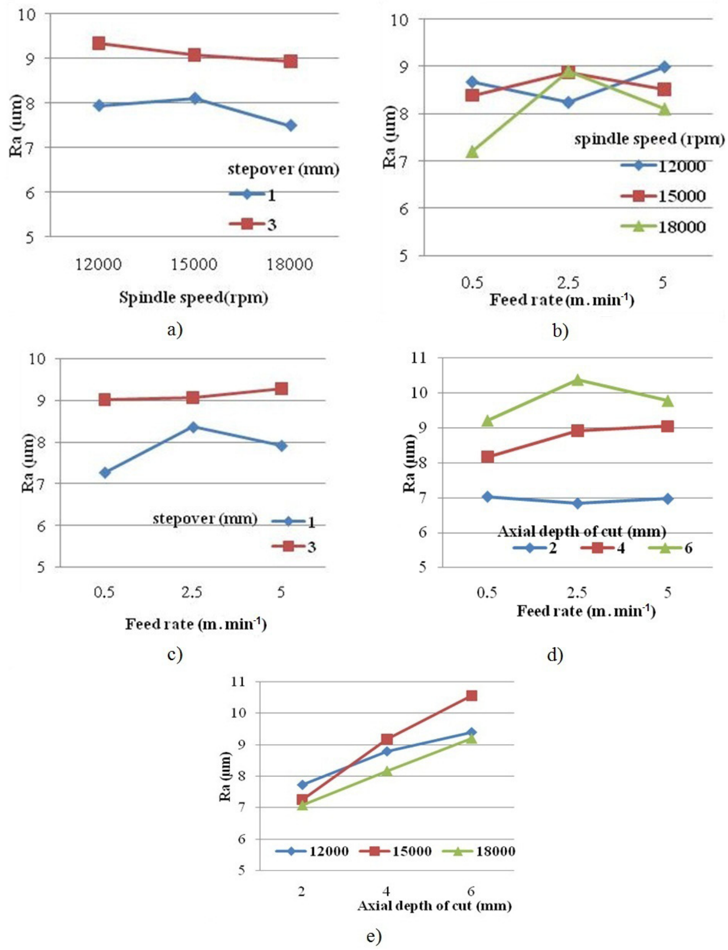


Fig. 5: The effect of dual interactions processing parameters on Ra, a) the interactions of spindle speed stepover b) the interactions of feed rate* spindle speed c)the interactions of feed rate* stepover d) the interactions of feed rate* axial depth of cut e) the interactions of axial depth of cut * spindle speed.*

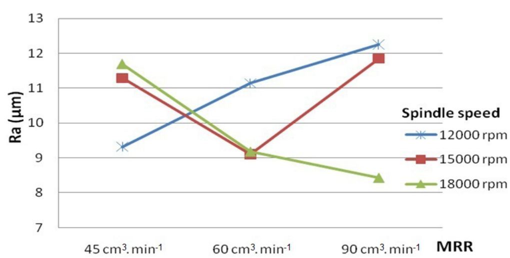


Fig. 6: The influence of spindle speed and MRR on surface roughness.

CONCLUSIONS

MDF is an appropriate for many common and industrial applications, especially, in the furniture industry. Among the several CNC industrial machining processes, milling is a fundamental machining operation. Face milling and groove milling are the most common milling operation encountered in furniture industry, especially customer specialized kitchen cabinet manufacturing. It is also widely used in a variety of manufacturing industries.

Therefore, this study was aimed at determining the effects of process parameters on face milling of the MDF material using CNC router. The results showed that higher spindle speed should be used in order to obtain larger material removal rates associated with minimal surface roughness and that surface roughness decrease with increasing spindle speed and increase with increasing stepover and feed rate. As stated in the literature, due to the difference density between the layers in MDF panels, surface roughness increase with increasing axial depth of cut. The high-density layers produce a better surface finish.

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