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Determination of Optimal Drilling Parameters of Massive Wooden Edge Glued Panels (EGP) and Medium Density Fiberboard using The Taguchi Method

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Abstract: In this paper, the optimization of computer numerical control (CNC) drilling parameters was conducted using the Taguchi experiment design on the drilling holes' inner surfaces roughness (*Ra*) massive wooden edge-glued panels (EGP) made of spruce (*Picea Orientalis* Link.), beech (*Fagus Orientalis* Lipsky), Iroko (*Chlorophora excelsa*) and Medium Density Fiberboard surfaced with synthetic resin sheet (MDFlam). Three drilling parameters and their effects on *Ra* were evaluated. These parameters included spindle speed, feed rate, and cutter type. Surface roughness measurements according to ISO 4287 were performed on the inner surfaces of the holes, and *Ra* values were obtained. An analysis of variance (ANOVA) was performed to identify the significant factors affecting the *Ra*. Optimum drilling parameter combinations were acquired by analyzing the signal-to-noise (S/N) ratio. It is shown that the most ideal result was obtained with a two flutes cutter (cutter number 2) at 18000 rpm and feed of 1750 mm/minute for in-hole roughness values of the MDFlam test sample. In the drilling operations performed with a double-entry cutter, the lowest roughness values were obtained in all materials.

Keywords: CNC, Drilling, MDFlam, wood, Taguchi, roughness

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1. INTRODUCTION

Wood and wood-based materials have been used as furniture and building construction materials for years (Davim, 2011). The inner surface of the holes' surface roughness of wood and wood-based materials is one of the most important properties characterizing the drilling process. The stylus method is commonly used for off-line roughness measurements of wood and wood-based materials (Sandak and Tanaka, 2003; Zhong *et al.*, 2013). Computer numerical control (CNC) has been used for the drilling of furniture materials. CNC has a lot of advantages for furniture manufacturing (Costes and Larricq,2002; Ohuchi and Murase, 2005; Karagoz *et al.*, 2011; Alves *et al.* 2015). The Taguchi Method (TM) can effectively determine the optimal combinations of machining parameters. TM uses a special design of orthogonal arrays (OA) to study entire parameter space with less experiment (Valarmathi *et al.*, 2013; Kacal ve Gülesin, 2011; Sofuoglu, 2015; Sofuoglu, 2017).

As can be observed from the literature, optimization studies on the machining of wood and wood-based materials were performed and *TM* was used in many of them. However, a lack of studies on wood and wood-based materials, especially in the applications of CNC drilling operations.

In this study, three crucial drilling parameters (spindle speed, feed rate, and cutter type) with an experimental setup made by the TM were investigated with a CNC machine. The R_a values were measured with a surface roughness measuring device on the drilled surface.

2. MATERIAL AND METHOD

In this study, the material used were 18-mm-thick; EGP made of spruce (*Picea Orientalis* Link.), and beech (*Fagus Orientalis* Lipsky), Iroko (*Chlorophora excelsa*), and MDFlam (MDF surfaced with synthetic resin sheet). The EGP are supplied by ERPAN from Simav/Kutahya, Turkey. EGP panels and MDFLam were selected randomly from the manufacturer. Experiments can be performed Skilled CNC

(Beysantaş A.Ş., Turkey) with a maximum 18000 rpm spindle speed and 2000 mm/min feed rate. The experiments were carried out with Netmak (Z2 and Z3) (Netmak group, Turkey) 8-mm-diameter CNC cutters made of solid carbide. New CNC cutters were used in drilling operation (Figure 1). The experiments evaluated three drilling parameters (spindle speed, feed rate, and cutter type) (Table 1). A total of 16x4=64 pieces were drilled on panels by a CNC router (Figure 2).

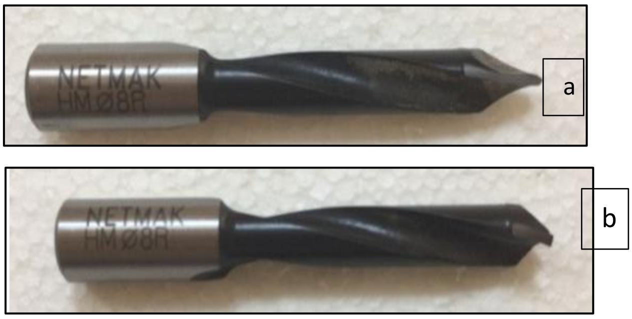

Figure 1. Solid carpide router cutters one flute (a) and two flutes (b) cutter types

Table 1. Machining parameters and levels for drilling

Machining parameter	Coded levels			
	Level 1	Level 2	Level 3	Level 4
Spindle speed (rpm)	12000	14000	16000	18000
Feed rate (mm/min)	1250	1500	1750	2000
Cutter type	1	2		

Time TR200 (China) surface roughness measurement device was used. The sampling length= 2.5 mm; the evaluation length *Lt*= 12.5 mm. measurement speed=10 mm/min, the diameter of the measurement needle= 4 µm, and the needle tip orientation= 90° were taken.

Wood drilling parameters were used as control factors, where two parameters were designed to have four levels and one parameter was designed to have two levels (Table 1). By TM, an L16 OA table with 16 rows was selected.

Figure 2. Skilled CNC 2040 CNC and drilling

Ra was measured on every drill hole three times. *Ra* is described in ISO 468 (2009), ISO 3274 (2005), and ISO 4287 (1997).

Statistical analyses (*S/N*, ANOVA) were performed by using MINITAB 19 software for a confidence level of 95%. The smaller-the-better quality characteristics for R_a *S/N* ratio.

3. RESULTS AND DISCUSSION

The experimental design of L16 and the experimental results are given in Table 2.

Table 2. Experimental Design using a TM (L16) and of Surface Roughness (R_a) (Aktaş, 2021)

Process no	Spindle speed (rpm)	Feed rate (mm/min)	Cutter type	MDFLam R_a µm	Spruce R_a µm	Beech R_a µm	Irako R_a µm
1	12000	1250	1	6.86	3.07	5.76	2.15
2	12000	1500	1	6.61	2.88	6.37	2.80
3	12000	1750	2	4.45	2.93	4.69	3.77
4	12000	2000	2	4.36	1.74	6.33	2.02
5	14000	1250	1	6.88	6.67	6.18	3.10
6	14000	1500	1	6.06	2.22	7.17	2.90
7	14000	1750	2	5.26	2.58	4.24	1.88
8	14000	2000	2	5.47	3.70	6.44	2.05
9	16000	1250	2	4.00	1.39	4.76	2.03
10	16000	1500	2	4.51	3.93	6.53	3.43
11	16000	1750	1	7.02	5.39	6.56	4.67
12	16000	2000	1	6.30	3.26	7.85	3.53
13	18000	1250	2	3.95	3.11	4.98	2.34
14	18000	1500	2	3.66	2.32	5.74	1.01
15	18000	1750	1	3.19	7.96	6.20	3.45
16	18000	2000	1	5.90	3.13	6.22	3.09

Table 3. ANOVA Results for R_a in MDFLam (Aktaş, 2021)

Source	Degrees of Freedom (DoF)	Sequential Sum of Squares (Adj SS)	Mean Sum of Squares (Adj MS)	F	P
Ra					
Spindle speed (rpm)	3	6.9711	2.3237	3.11	0.089
Feed rate (mm/min)	3	0.6720	0.2240	0.30	0.825
Cutter type	1	10.8257	10.8257	14.48	0.005
Residual error	8	5.9792	0.7474		
Total	15	24.4481			
Ra (for *S/N* ratios)					
Spindle speed (rpm)	3	23.629	7.8765	3.25	0.081
Feed rate (mm/min)	3	2.774	0.9246	0.38	0.769
Cutter type	1	26.737	26.7366	11.05	0.010
Residual error	8	19.363	2.4204		
Total	15	72.503			

Table 4. ANOVA Results for R_a in Spruce (Aktaş, 2021)

Source	DoF	Adj SS	Adj MS	F	P
Ra					
Spindle speed (rpm)	3	4.751	1.584	0.57	0.653
Feed rate (mm/min)	3	8.829	2.943	1.05	0.421
Cutter type	1	10.391	10.391	3.71	0.090
Residual error	8	22.384	2.798		
Total	15	46.355			
Ra (for *S/N* ratios)					
Spindle speed (rpm)	3	20.54	6.846	0.45	0.725
Feed rate (mm/min)	3	35.12	11.708	0.77	0.543
Cutter type	1	54.66	54.660	3.59	0.095
Residual error	8	121.83	15.229		
Total	15	232.15			

According to ANOVA results for MDFlam roughness (*Ra*) at 95% confidence level; it was seen that cutter type (0.05 > P = 0.005) was found to be a statistically significant difference, and spindle speed (0.05 < P = 0.089) and feed rate (0.05 < P = 0.825) did not make a statistically significant difference (Table 3). According to ANOVA results for spruce roughness (*Ra*) at 95% confidence level; it was seen that spindle speed (0.05 < P = 0.653), feed rate (0.05 < P = 0.421) and cutter type (0.05 < P = 0.090) did not make a statistically significant difference (Table 4).

Table 5. ANOVA Results for R_a in Beech (Aktaş, 2021)

Source	DoF	Adj SS	Adj MS	F	P
		Ra			
Spindle speed (rpm)	3	1.092	0.3640	1.30	0.340
Feed rate (mm/min)	3	5.518	1.8394	6.56	0.015
Cutter type	1	4.608	4.6082	16.43	0.004
Residual error	8	2.244	0.2805		
Total	15	13.463			
		Ra (for *S/N* ratios)			
Spindle speed (rpm)	3	1.827	0.6090	0.86	0.502
Feed rate (mm/min)	3	12.441	4.1469	5.82	0.021
Cutter type	1	10.593	10.5926	14.88	0.005
Residual error	8	5.696	0.7120		
Total	15	30.557			

According to ANOVA results for beech roughness (*Ra*) at 95% confidence level; it was seen that feed rate (0.05 < P = 0.015), cutter type (0.05 < P = 0.004) were found to be a statistically significant difference, and spindle speed (0.05 < P = 0.340) did not make a statistically significant difference (Table 5).

Table 6. ANOVA Results for R_a in Iroko(Aktaş, 2021)

Source	DoF	Adj SS	Adj MS	F	P
		Ra			
Spindle speed (rpm)	3	2.373	0.7909	1.49	0.288
Feed rate (mm/min)	3	2.603	0.8678	1.64	0.256
Cutter type	1	3.208	3.2077	6.06	0.039
Residual error	8	4.234	0.5292		
Total	15	12.418			
		Ra (for *S/N* ratios)			
Spindle speed (rpm)	3	24.16	8.055	0.99	0.446
Feed rate (mm/min)	3	22.85	7.618	0.93	0.468
Cutter type	1	42.02	42.015	5.15	0.053
Residual error	8	65.28	8.160		
Total	15	154.31			

According to ANOVA results for Iroko roughness (*Ra*) at 95% confidence level; it was seen that spindle speed (0.05 < P = 0.288), feed rate (0.05 < P = 0.256) and cutter type (0.05 < P = 0.039) did not make a statistically significant difference (Table 6).

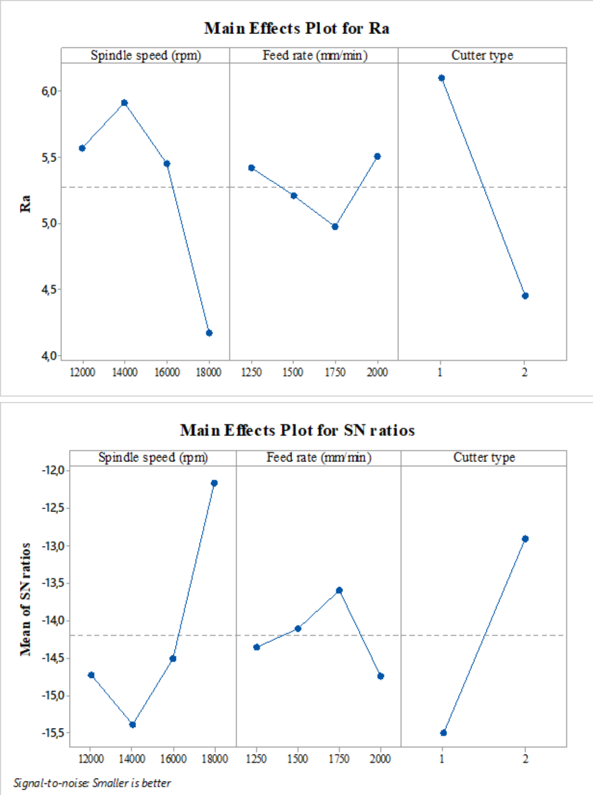

Figure 3. (a) MDFLam main effect plot for R_a; (b) mean *S/N* ratio for R_a

When the main effect and S/N ratio graphs for MDFlam *Ra* were examined (Figure 3), the lowest roughness values occurred at a speed of 18000 rpm, a feed rate of 1750 mm/min, and a cutter type 2.

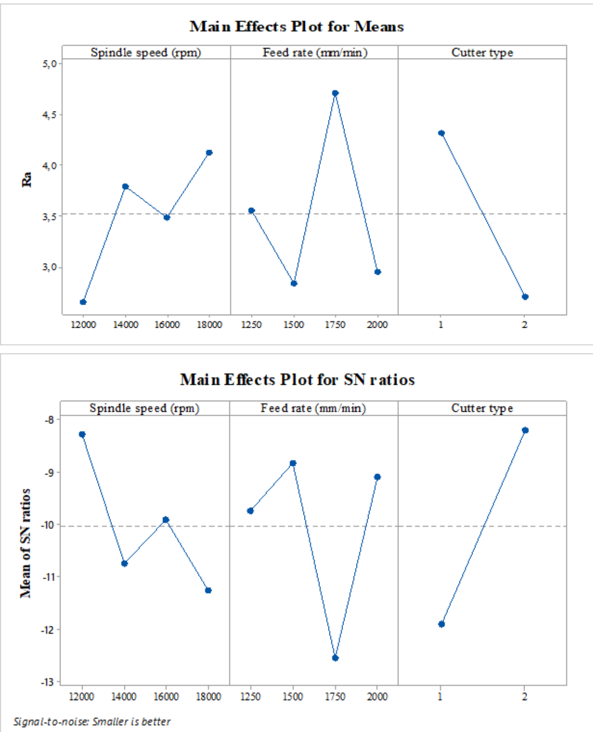

Figure 4. (a) Spruce main effect plot for R_a; (b) mean *S/N* ratio for R_a

When the main effect and S/N ratio graphs for spruce *Ra* were examined (Figure 4), the lowest roughness values occurred at a speed of 12000 rpm, a feed rate of 1500 mm/min, and a cutter type 2.

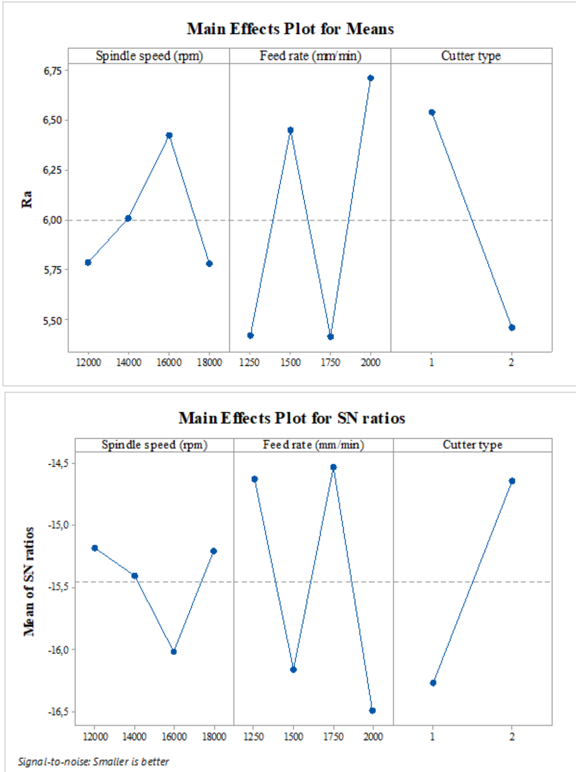

Figure 5. (a) Beech main effect plot for R_a; (b) mean *S/N* ratio for R_a

When the main effect and S/N ratio graphs for beech *Ra* were examined (Figure 5), the lowest roughness values occurred at a speed of 18000 rpm, a feed rate of 1750 mm/min, and a cutter type 2.

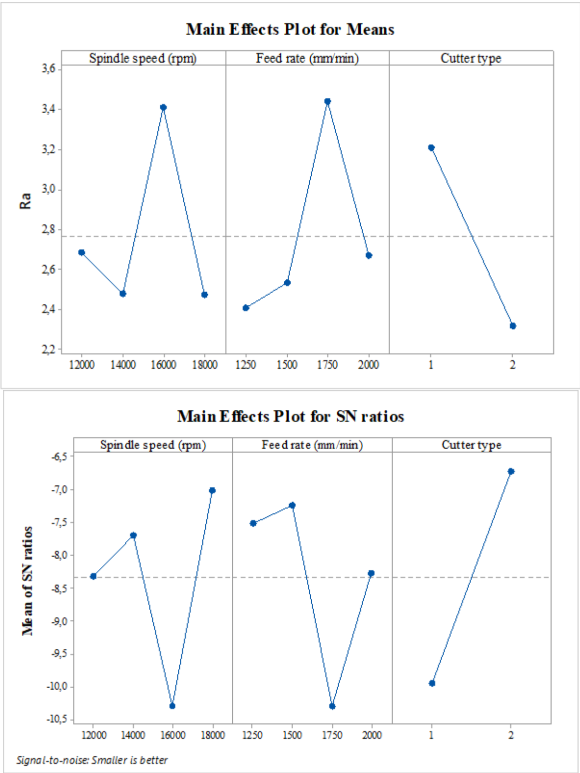

Figure 6. (a) Iroko main effect plot for R_a; (b) mean *S/N* ratio for R_a

When the main effect and S/N ratio graphs for Iroko *Ra* were examined (Figure 6), the lowest roughness values occurred at a speed of 18000 rpm, a feed rate of 1250 mm/min, and a cutter type 2.

In the literature; *Ra* decreased with the decreasing feed rates. Ra decreases with increasing spindle speed (Iskra and Tanaka 2005; Davim et al. 2009; Sutcu & Karagoz 2012; Sutcu 2013). According to some other literature; revolutions per minute were the most effective parameter for the changes in massive wooden table, which is made of Scotch pine drilling holes roughness (Kacal and Sofuoglu 2013).

Surface roughness values of drilling samples are important for determining surface quality.Average surface roughness (Ra) values were obtained as 14.58 µm, 11.18 µm, 15.17 µm, 11.94µm for ship auger bit drill and 7.06 µm, 13.02 µm, 7.91 µm, 7.55 µm for multiple spur bit drill inEuropean black pine, black poplar, sessile oak, and cedar of Lebanon respectively (Sofuoglu, *et.al*, 2015.

4. CONCLUSIONS

The following results can be drawn from the hole internal surface R_a, for the Medium Density Fiberboard with synthetic resin sheet (MDFlam), and the material used were; massive wooden edge-glued panels (EGP) made of spruce (*Picea Orientalis* Link.), beech (*Fagus Orientalis* Lipsky), Iroko (*Chlorophora excelsa*):

- The lowest roughness values occurred at a speed of 18000 rpm, a feed rate of 1750 mm/min, and a cutter type 2 for MDFlam,
- The lowest roughness values occurred at a speed of 12000 rpm, a feed rate of 1500 mm/min, and a cutter type 2 for spruce,
- The lowest roughness values occurred at a speed of 18000 rpm, a feed rate of 1750 mm/min and a cutter type 2 for beech.
- The lowest roughness values occurred at a speed of 18000 rpm, a feed rate of 1250 mm/min, and a cutter type 2 for ıroko.
- The lowest roughness values were obtained in drilling operations in all materials with the type 2 cutter.

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N/A

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Author Contributions
S.A: Construction of experiments, analysis of results. SDS: Experiment design, article writing and analysis of results. All authors have read and agreed to the published version of manuscript.

Conflict of Interest
The authors have no conflicts of interest to declare.

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