DETERMINATION OF WOOD CUTTING PARAMETERS USING TAGUCHI METHOD

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ABSTRACT

The determination of machining conditions for wood surface roughnesswas a crucial index in furniture industry.In this work,Taguchi method was used to determine the effective of CNC cutting parameters such as spindle speed, feed rate and depth of cuton arithmetic average roughness (R_a). Average surface roughness (R_a) values of the specimens of beech were measured using a stylus type equipment.An orthogonal array and analysis of variance (ANOVA) were conductedto investigate the machining factors.According to the results, the surface roughness decreased with the increase of spindle speed and decrease with the feed rate.The minimum surface roughnesswas obtained with spindle speed of 15000 rpm, feed rate of 2 m/min and depth of cut of 1mm.

Keywords: *Taguchi method, surface roughness, optimization, CNC, wood material*

I. INTRODUCTION

In a CNC processing operation, it was a significant issue to determine machining parameters for minimizing the surface roughness. Generally, selection of cutting parameters were decided based on experience or use of a handbook. These situations can be create problems in determining the optimum parameters. Furthermore, a large number of machining experiments required long time and very costly. Therefore, optimum parameters levels need to be determined by a systematic approach.In recent years, design of experiment techniques such as response surface method, full factorial design, Taguchi and robust design have been used to various engineering and machining problems [1-4]. In this work, an alternative approach based on the Taguchi method was conducted to evaluate the processing parameters. The Taguchi method is a powerful technique for determination of effective and optimum parameters. This method provides a simple, sufficient and systematic approach to optimize designs for performance, quality and cost [5-6]. The technique is used both qualitative and discrete parameters.Sofuoglu [7] investigated that optimization of CNC machining parameters such as cutter type, tool clearance strategy, spindle speed, feed rate and depth of cut were examined using Taguchi method on the surface quality of massive wooden panels made of Scots pine (*Pinus slyvestris* L.). ANOVA analysis was used to determine significant factors affecting the surface roughness (R_a and R_z) Optimal cutting performance for R_a and R_z was obtained for cutter 1, at a tool clearance strategy of a raster 16000 rpm spindle speed, 1000 mm/min feed rate and depth of 4 mm. Tiryaki et al. [8] used the Taguchi method in order to minimizing the surface roughness for sanding process. The process parameters were determined as feed rate, cutting depth, number of knives, annual ring (earlywood–latewood) and grit number of abrasive.The grit size was found the most significant factor on surface roughness of both beech and spruce woods. Benotmane and Zirouk [9] explored the woodturning performance using Taguchi methodology for dynamic system. According to the results, the method was usefully for woodturning process. Kumar et al.[10] studied that sundi wood dust reinforced epoxy composites were processed with six different filler content. Experiments were applied based on Taguchi L_{18} orthogonal array considering two parameters such as viz. speed and % filter wt. It was found that the speed was effective factor for load, tensile and flexural stress.

II. MATERIALS AND METHODS

Material Used

Beech pine (*Fagus orientalis* Lisky), species with intensive use in the furniture industry were selected for the study. The samples were prepared with the dimension of 100 mm x 40 mm x 15 mm for each procedure. Density level of specimen was measured randomly through 9 samples. Each sample was weighed and its dimensions were measured at an accuracy level of 0.1 g and 0.01 mm, respectively. Samples were conditioned in a climate room having a temperature of 20°C and relative humidity of 65% until they reach a moisture content of 11±1%. The density of the wood was measured as 0.435 g/cm³.The samples were conducted with 3-axis CNC router with 5.5 kW spindle power, a maximum spindle speed of 20000 rpm and a maximum feed rate of 10 m/min. Roughness measurement device is a stylus-based portable profilometer that is Sutronic-25 type equipment. Diamond stylus with a 5(µm) radius and 90° of tip angle was employed for roughness measurement. According to ISO 4287, there are two accepted roughness parameters, namely average roughness (R_a) and mean peak to valley height (R_z). In this study arithmetic average roughness (R_a) parameter was selected [11-13].

Taguchi Method

Taguchi technique was developed by Dr. Genichi Taguchi. The method is a structured approach for indicating the "best" combination of inputs to produce a product or service. The method consists of three steps: (1)System Design - create prototype product and process to produce it. (2) Parameter Design - find settings of process and product parameters which minimize variability. (3)Tolerance Design - tradeoff between loss to consumer and manufacturing costs [10].In this study, the machining parameters were determined as spindle speed, feed rate and depth of cut. The initial cutting parameters were as follows; spindle speed 11000 rpm; feed rate 6 m/min and depth of cut 1.5 mm. The feasible range for the machining parameters defined by varying the spindle speed in the range 9000-15000 rpm, the feed rate in the range 2-8 m/min, and depth of cut in the range 1-3 mm. In the CNC processing parameter design, three factors at three levels and each independent variable was coded at three levels between -1, 0 and +1. The experimental design used for this work is shown in Table 1.

Table 1: CNC procedure parameters and levels applied Taguchi design

Symbol	Parameters	Unit	Level (-1)	Level (0)	Level (+1)
n	Spindle speed	rpm	9000	12000	15000
f	Feed rate	m/min	2	5	8
d	Depth of cut	mm	1	2	3

In presented study, an L_9 orthogonal array with four columns and nine rows was determined. This array has eight degrees of freedom and three-level design parameters. A total number of 9 experiments were required for determining the cutting parameters. Statistical analysis (S/N, ANOVA) were applied by using Minitab software at confidence level of 95 %.Where the S represents signal term that mean the desirable value (S.D) for output characteristic and where the N represents noise term that mean undesirable value for the output characteristic. In these results, the S/N ratio is the ratio of the mean to the S.D. Taguchi applies the S/N ratio to measure the quality characteristic deviating from the desired value. In this experimental work, optimal cutting performance was performed with the smaller-the better quality characteristics for R_a . The smaller-the better quality characteristics can be expressed as:

$$\eta = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^{2}\right] \quad (1)$$

Where y is the observed value and n is the number of observations.

Table 2: L_9 orthogonal array design and results for R_a

RunOrder	Feed Rate (*f*,m/min)	Spindle Speed (*n*,rpm)	Depth of Cut (*d*,mm)	Roughness (Ra,µm)	S/N ratio
1	2	9000	2	2.03	-6,1858
2	5	9000	1	9.36	-19,4285
3	8	9000	3	21.72	-26,7404
4	2	12000	3	5.91	-15,4370
5	5	12000	1	10.12	-20,0885
6	8	12000	2	16.72	-24,4946
7	2	15000	1	2.78	-8,8734
8	5	15000	2	4.32	-12,6710
9	8	15000	3	21.14	-26,5044

III. RESULTS AND ANALYSIS

Variance Analysis (ANOVA)

Table 3 indicate the ANOVA conducted for R_a .The *p*-value serves as a tool for checking the significance of each coefficient. Value of *"prob>F"* are less than 0.05 indicating that the model term are significant. In this case *f* and *d*are significant factors. The experimental design of L_9, the experimental results and S/N ratios are given in Table 2. The optimal level of machining parameters was given in Figure 2.

Table 3: ANOVA of Taguchi design for R_a

Source	DF	SS	MS	*F*-Value	*P*-Value
n	2	5.007	2.503	2.74	0.267
f	2	427.889	156.259	171.26	0.006[a]
d	2	36.221	18.110	19.85	0.048[a]
Residual error	2	1.825	0.912		
Total	8	470.941			

DF: degrees of freedom, SS: Sum of squares, *F*: *F*-test value and *P*:error variance [a] At a given response, parameters belonging to the filled cells are effective within 95 %reliability interval.

Model Checking

In order to check the data for normality, it is best to construct an NPP (Normal Probability Plot) of the residuals. Residual is the mean difference between the observed value and the predicted value. Figure 1 **a** shows that the residuals generally fall on a straight line implying that the errors were disturbed normally, meaning was the experimental data come from a normal population. Figure 1 **b** shows plot of the residuals versus the fitted values for the surface roughness data. As the result of the residuals no unusual structure was apparent.

(a) (b)

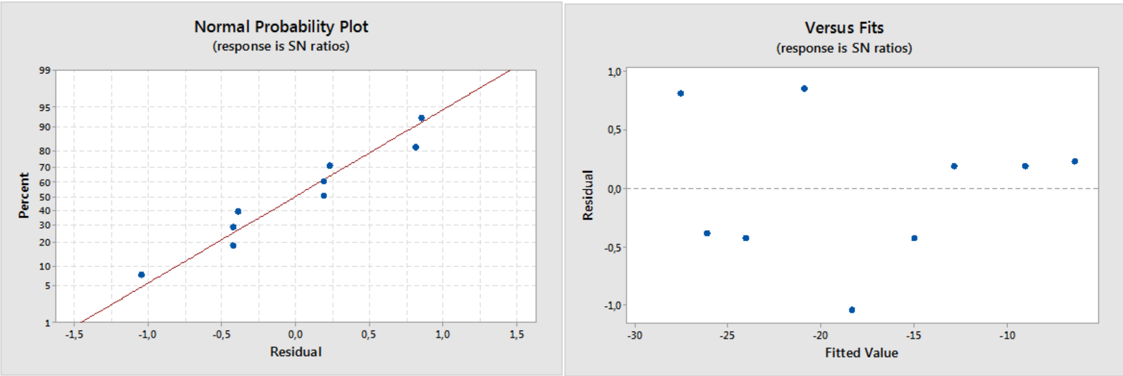

Fig. 1. a NPP of residuals for the surface roughness **b** Plot of residuals versus fitted values

Surface Graphs and Analysis

According to Figure 2 the increase spindle speed resulted in a decrease in the surface roughness. The surface roughness decreased with higher spindle speed. Also, minimum surface roughness value was obtained with lower feed rate and lower depth of cut. The optimal cutting performance for R_a was obtained with 15000 rpm spindle speed (Level 3), 2 m/min feed rate (Level 1) and 1 mm depth of cut (Level 1).

(a) (b)

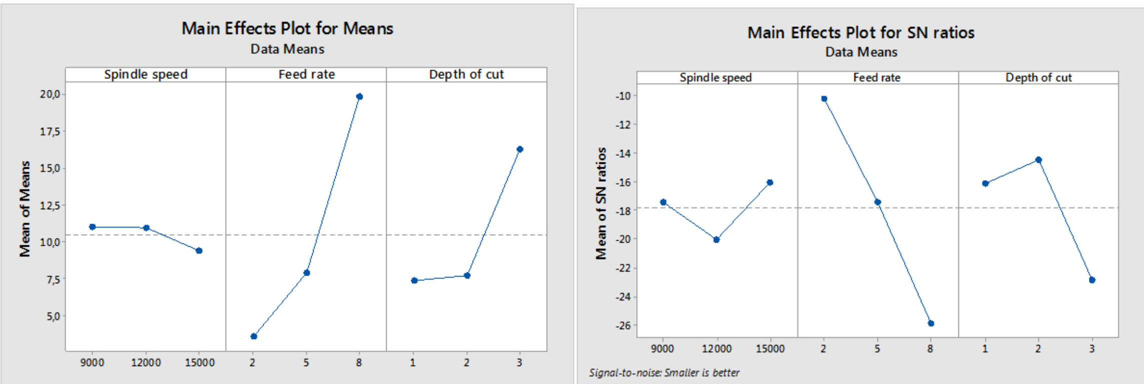

Fig.2.a Main effect plot for means (R_a). **b** mean S/N ratio (R_a)

Confirmation Test

Conformation test consist of two steps: First, the optimal level of the design parameters is determined. Second step is to predict and verify the improvement of the quality characteristic employing the optimal level of design parameters. Table 4 shows that the predicted and real machining values for surface roughness.

Table: 4 Conformation test for R_a

Parameters of Taguchi design	Starting cutting parameters	Optimal cutting parameters	
		Prediction	Experimental
Level	F3N1D3	F1N3D1	F1N3D1
R_a (µm)	21.72	3.11	2.78
S/N ratio (dB)	-26.7404	-9.06	-8.8734
Improvement of S/N Ratio	17.87		
Prediction error (dB)	2.05 %		

IV. CONCLUSION

In this work, effect of machining of spruce wood, the surface roughness characteristics were investigated. The optimization process was conducted Taguchi design. The results is summarized as follows:

- Analysis of variance (ANOVA) demonstrates that the surface roughness R_a was influenced by feed rate and depth of cut.
- The results were analyzed using main effect plots. The surface graphsdemonstrated the surface roughness increased with higher feed rate, lower spindle speed and higher depth of cut.
- Smoother wood surface was investigated with spindle speed of 15000 rpm, feed rate of 2 m/min and depth of cut of 1mm.
- According to conformation tests, prediction error value was determined as 2.05%.
- The Taguchi method was adequate for solving the surface roughness problem for CNC processing.

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