International Journal of Information, Engineering & Technology

Volume 11, Issue 2, PP 105-113, ISSN: 2360-9194, December, 2020
Double Blind Peer Reviewed International Research Journal
garcjournalssubmit@gmail.com
Journal Series: Global Academic Research Consortium (garc)

An Investigation of the Optimal Cutting Condition in Meranti (Shorea Leprosula) Wood in Turning Process using Taguchi Method

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Abstract: *Problem statement: In wood machining operation, the quality of surface finished is an important requirement for many turned work pieces. Thus, the choice of optimized cutting parameters is very important for controlling the required surface quality. Approach: The focus of present experimental study is to optimize the cutting parameters using a single performance measure which is the surface roughness. Optimal cutting parameters for the surface roughness measure were obtained employing Taguchi techniques. The orthogonal array, signal to noise ratio and analysis of variance were employed to study the performance characteristics in turning operation.Results:The experimental results showed that feed rate had no effect on surface roughness.Moreover,it was found from the experiment that the factors affecting a surface roughness were cutting speed and depth of cut, with having tendency for reduction of roughness value at higher depth of cut and greater cutting speed.Conclusion:Thus,it is possible to increase machine utilization and decrease production cost in automated manufacturing environment.*

Key words: *Surface roughness, Taguchi parameter design, turning, Meranti wood*

INTRODUCTION

In the past few years, wood machining has often been treated as the last factor on improving productivity as an integrated part in furniture manufacturing; nevertheless, with growing concern on the future supply of wood resources, it becomes significant for researchers to gain a better understanding of wood machining process nowadays. Currently, Meranti (Shorea Leprosula) wood becomes more popular as an important raw material in Malaysia furniture and wooden tools manufacturing industry due to unique properties of Meranti such as excellent light red wood texture and color like high quality hardwoods. In addition, Meranti wood can be generally obtained from Meranti tree plants which are mostly found in Southeast Asian countries. Consequently, in order to improve the productivity of using Meranti wood for furniture manufacturing industry, more understanding of the wood machining process and its optimal cutting condition are needed to acquire high quality wood products and to reduce production time with less tooling cost and less waste materials.

Wood machining is normally performed under very high cutting speed with the extremely sharp cutting edges. It is a predominantly abrasive process; therefore the erosion of the cutting tool material is the main wear mechanism. Low wedge angles are necessary for machining massive wood which generally give a better surface quality; however, the lower the angle the higher the wear (Endler, 1999). The amount of wear generally decreases with the increase in hardness, the decrease in grain size and the decrease in binder content of the cutting tool material. Several wear mechanisms may contribute to the overall wear of the cutting tool. Among these wear mechanisms are gross fracture or chipping, abrasion, erosion, micro fracture, chemical and electrochemical corrosion as well as oxidation. Corrosion can be easily removed from the cutting edge by abrasion depending on the cutting condition e.g., moisture content, composition, etc. (Sheikh-Ahmad and Bailey, 1999). Some wears could occur through tool edge chipping when wood products which have low moisture content (dry) are machined. Tool life and tool performance in a given operation improve considerably when the Cemented Tungsten Carbides are used in place of either high carbon steel or high speed steels (Bailey, 1983).

In general, most research has focused on primary wood production processes needed to produce materials with specific characteristics. There are many different methods to cut materials; routing process is often used to compare different material wear on the cutting tool. There are distinct characteristics in tool wear and surface roughness among different wood fiber plastic products. Differences also exist when these materials are compared to solid wood. A better understanding of the necessary process parameters to cut these materials will lead to the improved results with respect to tool wear and surface roughness (Buehlmann, 2001). Researchers have attempted to gain more understanding in wood machining process. The relationship between the cutting process parameters such as feed rate, cutting speed and wood machining productivity was developed (Diei and Dornfeld, 1987). The effects of tool wear, cutting direction, spindle speed on edge chipping of wood board using a Pinacho S90/200 lathe machine was studied. The relationship of work piece quality, tool wear and machining conditions was also verified with the empirical monitoring indices (Rodkwan, 2000).

Taguchi and Analysis Of Variance (ANOVA) can conveniently optimize the cutting parameters with several experimental runs well designed. Taguchi parameter design can optimize the performance characteristics through the settings of design parameters and reduce the sensitivity of the system performance to source of variation (Berger and Maurer, 2002; Ryan, 2000). On the other hand, Analysis Of Variance ANOVA used to identify the most significant variables and interaction effects (Henderson, 2006; Ryan, 2000).

The mechanics of machining was investigated for other materials, besides metals and wood, such as elastomers were also performed (Rodkwan and Strenkowski, 2002, 2003). In their research, the effects of various machining parameters on chip morphology, surface roughness and the associated machining force were examined using the orthogonal cutting test of elastomers. The feed rate and cutting speed were found to have significant effect on the type of chips generated during orthogonal cutting (Rodkwan, 2002).

The objective of this work is to investigate the effect of various machining parameters such as spindle speed, feed rate, and depth of cut on product quality through machining process on a manual lathe machine PinachoS-90/200 Model. Additionally, optimal cutting conditions on Meranti wood machining are determined using a statistical procedure.

MATERIALS AND METHODS

Experimental procedures and conditions: In this study, Meranti (Shorea Leprosula) wood of 2 inch diameter and 2-3 feet long for each of the sample which 9 samples are used as work material for experimentation using a lathe turning machine. The density at 13.82% moisture content is 710kg/m^3.High speed steel Plansee Tizit Model DGGT Grade H10T with 6.0% carbon was used throughout the experiment as the cutting tool. All tests were performed dry.

Cutting speed, feed rate and depth of cut were selected as the machining parameters to analyze their effect on surface roughness. A total of 9 experiments based on Taguchi's L9 (3^4) orthogonal array were carried out with different combinations of the levels of the input parameters. Among them, the settings of cutting speed include 950, 1150 and 1400 rpm; those of feed rate include 0.05, 0.1, 0.15 mm/rev; the depth of cut is set at 0.5, 1.0 and 1.5 mm. Experimental planning was prepared by using cutting parameters and test conditions that were advised for a couple of tool-work piece by tool manufacturers and the information available in the literature. A schematic diagram of the experimental set-up is shown in Figure 1.

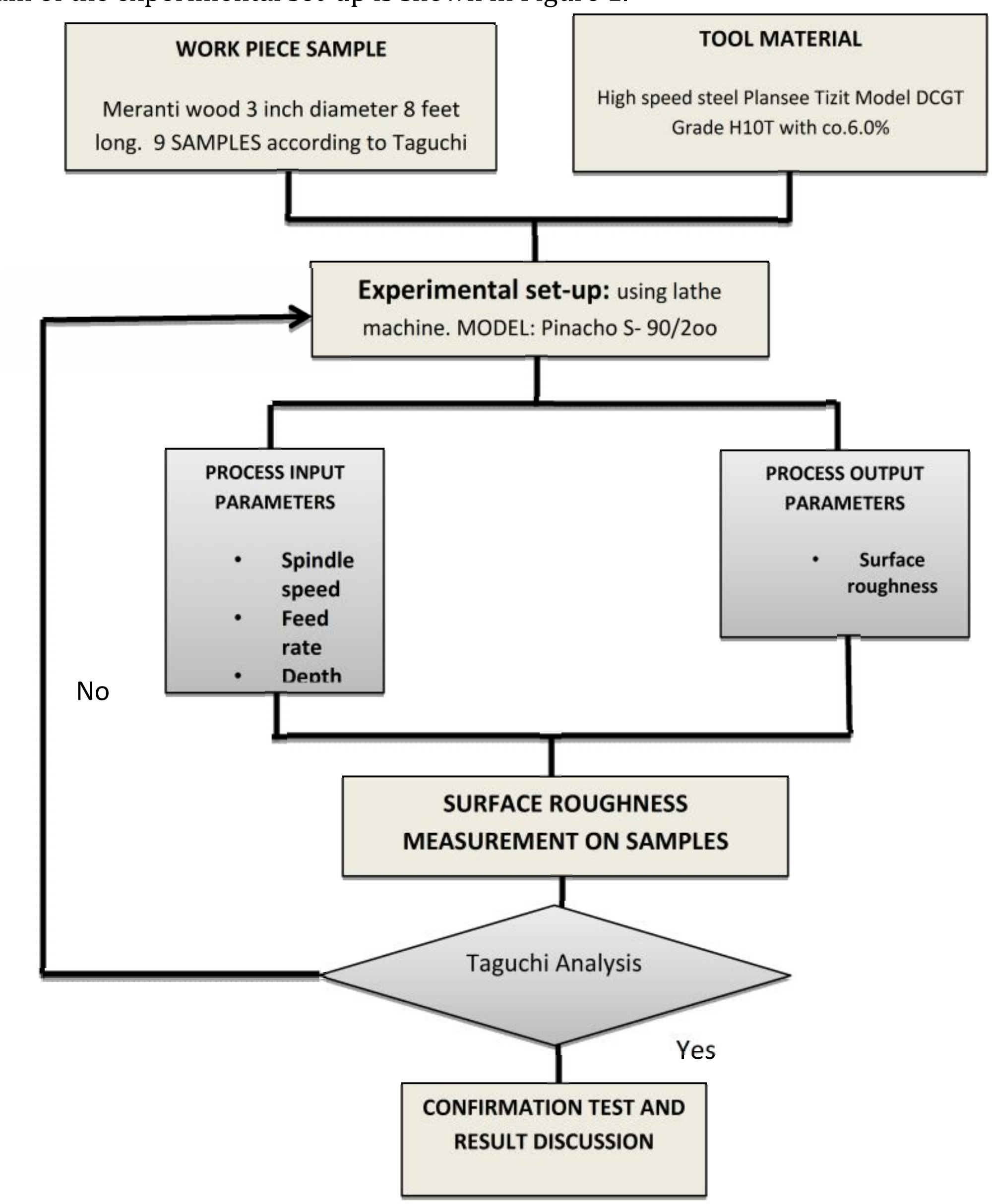

Figure 3 Methodology Flow chart.

The amount of standard surface roughness parameter (Arithmetic average deviation from the mean line Ra) is carried out using surface roughness tester model Mahr S2 Perthometer (produced by Mahr GMbH, Germany). Three measurements for work piece surface roughness were made and averaged for each test. This set-up was connected to computer using necessary hardware and software for data acquisition.

Taguchi method is being applied in to select the control factors levels (Cutting speed, Feed rate and depth of cut) that minimize the effect of noise factors on the response (surface roughness) and to come up with the optimal surface roughness value.

The goal of the experimental work was to investigate the effect of cutting parameters on surface roughness and to establish a correlation between them to determine which one has the most effect on the surface roughness. Experiment were planned according to Taguchi's L9(3^4) orthogonal array, which has 9 rows corresponding to the number of test with 3 columns at three levels, as shown in Table 1.The factors and interactions are assigned to the columns.

Table 1: Orthogonal array L9 (3^4) of Taguchi

Experiment No	Cutting Parameter Level		
	A (Cuttings peed)	B (Feed rate)	C (Depth of cut)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

It means a total of 9 experimental numbers must be conducted using the combination of levels for each independent factor (cutting speed (A), feed rate (B), and depth of cut (C)),as shown in Table 1.The orthogonal array is chosen due to its capability to check the interaction among factors.

The procedure for these test were to measure each work piece surface roughness and transformed into a Signal to Noise (S/N) ratio.

There are three categories of quality characteristic in the analysis of the S/N ratio, (i) the-lower-the-better, (ii) the-higher-the-better and (iii) the-nominal-the- better. Regardless of the category of the quality characteristic, process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. The category the-lower-the-better was used to calculate the S/N ratio for both quality characteristics surface roughness and work piece surface temperature, according to the equation:

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

Where:
η = Signal to noise ratio
n = Number of repetitions of experiment
y_i = Measured value of quality characteristic

In addition, a statistical Analysis Of Variance (ANOVA) is performed to see which process parameters are significantly affecting the responses (surface roughness, Ra).

RESULTS

The measured values of surface roughness for the machined surfaces corresponding to all the experimental runs are given in Table 2.

Signal to noise ratio: Analysis of the influence of each control factor (S, F and D) on the surface roughness (Ra average) has been performed with a so-called signal to noise ratio response table. Response table of S/N ratio for surface roughness are shown in Table 3.It show the S/N ratio at each level of control factor and how it is changed when settings of each control factor are changed from one level to other.

The influence of each control factor can be more clearly presented with response graph. Response graph for the control factors are shown in figure 2,the slope of the line which connects between the levels can be clearly show the power of the influence of each control factor.

Table 2.Experimental result for Ra (average) from three different readings

S	F	D	Ra_1	Ra_2	Ra_3	Average
950	0.05	0.5	1.657	1.012	1.464	377667
950	0.1	1	1.26	1.284	1.227	1.257
950	0.15	1.5	1.249	1.261	1.294	1.268
1150	0.05	1	1.378	1.359	1.362	366333
1150	0.1	1.5	0.902	0.903	0.998	934333

1150	0.15	0.5	1.1789	1.179	1.148	168633
1400	0.05	1.5	0.808	0.85	0.883	0.847
1400	0.1	0.5	1.006	1.063	1.482	183667
1400	0.15	1	1.171	1.244	1.858	424333

S: Cutting speed; F: Feed rate; D: Depth of cut: Ra average; Average experimental surface roughness

Table 3: Response table for S/N ratio (smaller is better) for Ra

Level	S	F	D
1	-2.27732	-1.35056	-1.86701
2	-1.15825	-0.95378	-2.59002
3	-1.03150	-2.16273	-0.01003
Delta	1.24583	1.20895	2.57999
Rank	2	3	1

Analysis of variance ANOVA: The experimental results were analyzed with analysis of variance (ANOVA) using one-way ANOVA analysis, which is used for identify each individual factors significantly affecting the performance measures. The results of ANOVA with Signal to noise ratio are shown in Table 4, 5 and 6 respectively. This analysis was carried out for significance level of α = 0.05, i.e. for a confidence level of 95%.

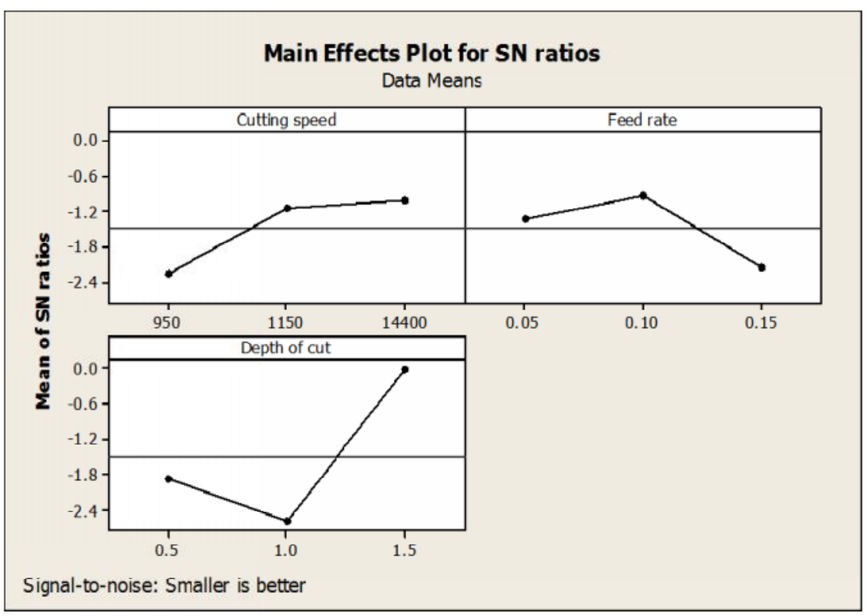

Figure 2. Main effect plot for S/N ratio for surface roughness (Ra)

Table 4: One-way ANOVA: Signal to noise ratio versus S

Source	DF	SS	MS	F	P-value
S	2	2.82	1.41	0.52	0.621
Error	6	16.36	2.73		
Total	8	19.18			
S= 1.651		R-Sq = 14.70%		R-Sq (adj) = 0.00%	

Table 5: One –way ANOVA: Signal to noise ratio versus F

Source	DF	SS	F	P
F	2	2.28	1.14	0.40
Error	6	16.91	2.82	0.684
Total	8	19.18		
S=1.679		R=Sq=11.88%		R-Sq(adj)=0.00%

Table 6:One-way ANOVA: Signal to noise ratio versus D

Source	DF	SS	MS	F	P
D	2	10.68	5.31	3.73	0.089
Error	6	8.56			
Total	8	19.18			
S=1.194		R-Sq=55.40%		R-Sq(adj)=40.53	

DISCUSSION

It can be seen from table 3 and according to the rank value for each control factor that the depth of cut had the strongest influence on surface roughness followed by cutting speed and last by feed rate.

From the main effects plot for S/N ratio for surface roughness Figure 2, the surface roughness appear to be an almost linear increasing function of depth of cut (D) and decreasing function of cutting speed (S).Thus, in order to reduce the level of surface roughness, depth of cut (D) should be set at its highest level (1.5mm) and the cutting speed (S) as well to its highest level (1400rpm) too. Also, high level (0.15rev/mm) or low level (0.05rev/mm) of feed rate (F), may be preferred, while the effect of F has not been found statistically significant (p-value= 0.40).

From Table 4, 5, and 6, analysis of variance ANOVA for surface roughness. It can be found that depth of cut has the slightest significant cutting parameters for affecting surface roughness. The change of the feed rate in Table 2 has an insignificant effect on surface roughness.

Therefore, based on the S/N ratio and ANOVA analysis, the optimal cutting parameters for surface roughness are the depth of cut at level 3, the cutting speed at level 3 and feed rate at level 2.

CONCLUSION

This study discussed an application of the Taguchi method for optimizing the cutting parameters in turning operations using single performance measure which is the surface roughness (Ra). From this study, the following conclusions could be reached with a fair amount of confidence: Regardless of the category of the quality characteristic, the-lower-the better for surface roughness the lowest feed rate (F = 0.05 mm rev? 1), the highest cutting speed (S = 1400 rpm) and highest depth of cut (D = 1.5 mm) lead to optimal surface roughness value. Finally the experimental results show that better surface quality in Meranti wood can be achieved by controlling the cutting parameters for better optimization.

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