WALAILAK JOURNAL

http://wjst.wu.ac.th Physical Sciences

An Investigation of the Optimal Cutting Conditions in Coconut Wood and Palmyra Palm Wood Turning Process Using Design of Experiment

Surasit RAWANGWONG*, Jaknarin CHATTHONG, Julaluk RODJANANUGOON and Worapong BOONCHOUYTAN

Department of Industrial Engineering, Rajamangala University of Technology Srivijaya, Songkhla 90000, Thailand

(*Corresponding author's e-mail: sitnong2@yahoo.co.th)

Received: 8 March 2012, Revised: 8 June 2012, Accepted: 16 April 2013

Abstract

The purpose of this research is to investigate the effect of factors on the surface roughness in the coconut wood and palmyra palm wood turning process for manufacturing furniture parts using carbide cutting tools. The main factors, namely, cutting speed, feed rate and depth of cut were investigated for the optimum surface roughness in furniture manufacturing process. Normally, an acceptable surface roughness is between 3.0 - 9.0 μm before the sanding process. The result of preliminary trial shows that the depth of cut had no effect on surface roughness. Moreover, it was found from the experiment that the factors affecting surface roughness were cutting speed and feed rate, with a tendency for reduction of roughness value at lower feed rate and greater cutting speed. Therefore, in the turning process of coconut wood, it was possible to determine a cutting condition by means of the equation R_a = 3.90 - 0.00375 Cutting Speed+7.93 Feed Rate, This equation can be best used with a limitation of cutting speed at 170 - 353 m/min, feed rate at 0.05 - 0.16 mm/rev and depth of cut at 1 mm. In the turning process of palmyra palm wood, equation R_a = 3.38 - 0.00164 Cutting Speed+10.8 Feed Rate, This equation can be best used with a limitation of cutting speed at 188 - 392 m/min, feed rate at 0.05 - 0.12 mm/rev and maximum depth of cut at 1 mm. To confirm the experiment result, a comparison between the equation value and an actual value by estimating a prediction error value was calculated with the surface roughness and margin of error not over 10 %. The result from the experiment of mean absolute percentage error of the equation of surface roughness is 4.28 % for coconut wood and 3.47 % for palmyra palm wood, which is less than the predicted error value and is acceptable.

Keywords: Design of experiment, turning, coconut wood, palmyra palm wood, surface roughness

Introduction

In the past few years, wood machining has often been treated as the last factor in 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 processes nowadays [1]. Currently, coconut wood is becoming more popular as an important raw material in the Thailand furniture manufacturing industry due to several properties of coconut wood, such as the beautiful wood pattern, durability and the high quality of the hardwood. In addition, coconut wood is found in Southern Thailand. Consequently, in order to improve the productivity of using coconut wood in the furniture manufacturing industry, more understanding of the coconut wood machining process and its optimal cutting condition is needed to acquire high quality wood products and to reduce production time with less tooling costs and less wasted materials. Almost all parts of coconut wood can be useful in the daily life of human beings. Its fruit can also be used as main dessert ingredients, and its shell as fuel yielding high heat. Moreover, its trunk can be made into wood planks and posts which are resistant to rain, sunlight and friction. Coconut wood is very popular for furniture production, like tables, chairs, beds, and souvenirs such as mortars, wooden plates, spoons, vases, bracelets, candlesticks etc. due to its beautiful wood pattern, durability and reasonable price.

Due to its hard wood with grain, a workpiece made of coconut wood often has surface roughness resulting from planning, turning or cutting processes. The workpiece still needs further furnishing, leading to a size change in certain parts of a furnished workpiece. Several factors affect the surface roughness, such as the cutting blade, cutting speed, feed rate and depth of cut [2]. In general practice, a worker provides his skills and relative experience as an indicator for justification, which can decrease precision.

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; a routing process is often used to compare material wear on different cutting tools. There are distinct characteristics in tool wear and surface roughness among different wood fiber and 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 improved results with respect to tool wear and surface roughness [3-9]. Researchers have attempted to gain more understanding in wood machining processes. A relationship between the cutting process parameters such as feed rate, cutting speed and wood machining productivity was developed.

Cutting wood is a major manufacturing process in the furniture industry, and the manufacturing of turning component with a cutting tool is one of the important machining processes. The machining process is used in both roughing and finishing operations. Thus, in the forming process, turning, machining, and milling the surface of the piece may cause loss of material. Such problems may be caused by several factors such as material, cutting speed, feed rate, depth of cut, and lack of workers expertise. This research, therefore, is interested in investigating proper conditions for coconut wood and palmyra palm wood turning processes, in order to benefit the furniture industry and the component manufacturing industry and to reduce time and cost for a better quality product. In addition, the research may be useful for any future research on a similar topic.

Equipment and tools

This research study aimed to investigate the effect of main factors on surface roughness in the coconut wood and palmyra palm wood turning process. The following equipment and instruments were used.

1) A cutting tool: Carbide cutting tool - Plansee Tizit (CERA TIZIT) Model DCGT 11T308FN-27 Grade H10T with Co. 6.0 %.

2) A turning machine: Harrison M 300R

3) Wood piece samples: coconut wood and palmyra palm wood bars with a diameter of 45 mm, 250 mm in length and humidity 10 - 13 %.

4) A surface roughness measuring device: Model Mitutoyo Surf Test 301

5) A humidity measuring instrument: Model DT-129

Methodology

There were four main procedures that served the purposes of conducting this study. The first procedure was to investigate the sample size in order to design the turning process. The second was to study the expected factors in making an effect on surface roughness in the coconut wood and palmyra palm wood turning process. Third was a pilot treatment to examine the optimum surface roughness, and last was to take a real treatment in order to confirm the results. These are detailed as follows:

Experiment phase 1

The sample size to design the coconut wood and palmyra palm wood turning machine was investigated by using Program Minitab R.15 with statistic reliability and significance at 95 and 5 % respectively.

Experiment phase 2

This was a preliminary experiment to identify factors which could affect surface roughness. A completely randomized block design [10] was applied with a repetition of 3 times and a measuring of 5 times. Minitab R.15 was employed to calculate statistic values and to analyze the 2^3 factorial design. The three factors and the responsive surface roughness values are shown in **Table 1** for coconut wood and **Table 2** for palmyra palm wood.

Table 1 Specification of preliminary variables for coconut wood.

Factor	High	Low
Cutting speed (m/min)	353	170
Feed rate (mm/rev)	0.3	0.05
Depth of cut (mm)	2	0.5

Table 2 Specification of preliminary variables for palmyra palm wood.

Factor	High	Low
Cutting speed (m/min)	240	169
Feed rate (mm/rev)	0.1	0.03
Depth of cut (mm)	2	0.5

Table 3 Specification of variables in experiment phase 3 for coconut wood.

Factor	Level 1	Level 2	Level 3
Cutting speed (m/min)	170	240	353
Feed rate (mm/rev)	0.05	0.1	0.16
Depth of cut (mm)	1	1	1

Table 4 Specification of variables in experiment phase 3 for palmyra palm wood.

Factor	Level 1	Level 2	Level 3
Cutting speed (m/min)	188	267	392
Feed rate (mm/rev)	0.05	0.1	0.12
Depth of cut (mm)	1	1	1

Experiment phase 3

This was to adjust the variable values to specify roughness values. General factorial design was utilized to adjust variable values to see the responsive effect. The experiment included 3 speeds of cutting speed, 3 rates of feed rates and a depth of cut which was fixed at 1 mm. and set as a stable variable due to its slight affect on roughness as shown in **Table 3**. To reduce variance, leading to higher reliability, the experiment in this phase was carried out 12 times and measured 5 times. **Table 3** shows the specification of variables in the experiment for coconut wood and **Table 4** for palmyra palm wood.

Experiment phase 4

This was to take a real treatment in order to confirm the results. This treatment was tried out to confirm the conformation of each treatment by using a linear equation of experiment phase 3 to predict the surface roughness. The prediction was done by randomly selecting 6 cutting conditions and replicating each condition 5 times. The margin of error was not over 5 %.

Experimental result of coconut wood

Results of sampling sizes

The experiment for finding the sampling sizes used statistical values in data analysis. The reliability was at 95 % or significance at 5 %. The feed rate was at 0.10 mm/rev; the cutting speed was at 240 m/min; the depth of cut was at 1 mm. The twelve repeated treatments revealed that the mean average of surface roughness was at 3.331 µm and the standard deviation was 0.382 µm. Furthermore, the result of sample size investigation was a 5-sampled size.

Results and result analysis of experiment phase 2

This was to experiment surface roughness affected by the related factors. The completely randomized block design and Minitab R.15 were applied to calculate statistic values and to analyze the results by Multi Factorial Factors. The statistic values employed were a change rate (F-Ratio) and a reliability value at 95 % with a significance of 5 %.

The surface roughness values obtained from the planned design indicates that the decision coefficient (R^2) equaled 88.70 % and Adjust R^2 was 83.75 %. This means that if the variance value of the data is 100 µm^2, the variance value of 88.70 µm^2 can be explained with a regression model, whereas the remaining volume is not explainable due to uncontrollable variables.

Since the values of feed rate and cutting speed can affect variance of the measured data of surface roughness, it can be concluded that the experiment design is accurate and appropriate. Thus, the results of variance can be used in a further analysis. The analyzed results are presented in **Table 5**.

Table 5 and **Figure 2** reveal that the main factor affecting the surface roughness of coconut wood is cutting speed and feed rate with a tendency for a higher surface roughness value when the feed rate was increased from 0.05 to 0.20 mm/rev. In addition, a greater value of feed rate and a lower cutting speed led to an increase of surface roughness value. The information in **Table 5** shows that no other factors affected the surface roughness.

Table 5 Analyzed results of variance values of surface roughness values for coconut wood.

Analysis of Variance for R_a, using Adjusted SS for tests						
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Cutting speed	1	1.9513	1.9513	1.9513	29.13	0.000
Feed rate	1	5.9700	5.9700	5.9700	89.14	0.000
Depth of cut	1	0.1266	0.1266	0.1266	1.89	0.188
Cutting speed*Feed rate	1	0.0821	0.0821	0.0821	1.23	0.285
Cutting speed*Depth of cut	1	0.2249	0.2249	0.2249	3.36	0.086
Feed rate*Depth of cut	1	0.0027	0.0027	0.0027	0.04	0.842
Cutting speed*Feed rate*Depth of cut	1	0.0520	0.0520	0.0520	0.78	0.391
Error	16	1.0716	1.0716	0.0670		
Total	23	9.4812				
S = 0.258795 R^2 = 88.70 % R^2 (adj) = 83.75 %						

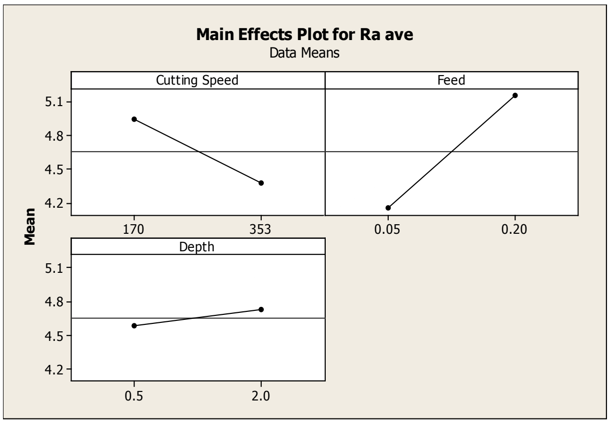

Figure 1 Changes in surface roughness arising from level changes of main factors for coconut wood.

Table 6 Analysis of adjusting variable values to find surface roughness values for coconut wood.

Analysis of Variance in R_a, using Adjusted SS for Tests						
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Cutting speed	2	10.1010	10.1010	5.0505	123.15	0.000
Feed rate	2	16.3738	16.3738	8.1869	199.63	0.000
Cutting speed*Feed rate	4	1.1559	1.1559	0.2890	7.05	0.000
Error	99	4.0600	4.0600	0.0410		
Total	107	31.6907				
S = 0.202508 R^2 = 87.19 % R^2 (adj) = 86.15 %						

Results and result analysis of experiment phase 3

This test was undertaken to adjust variable values to find surface roughness values. The result shows that the main factors affecting surface roughness of coconut wood are feed rate and cutting speed. The result indicates that the decision coefficient (R^2) is 87.19 % and adjust R^2 was 86.15 %. This means that if the variance value of the data is 100 $\mu m^{2,}$ the variance value of 87.19 μm^2 can be explained with a regression model, whereas the remaining volume is not explainable due to uncontrollable variables.

Table 6 shows the result from experiment phase 3 concerning surface roughness values, indicating that the main factor most affecting the value of surface roughness is feed rate, whereas cutting speed is rated second. Moreover, it was found that the interaction value among the factors has an effect on surface roughness.

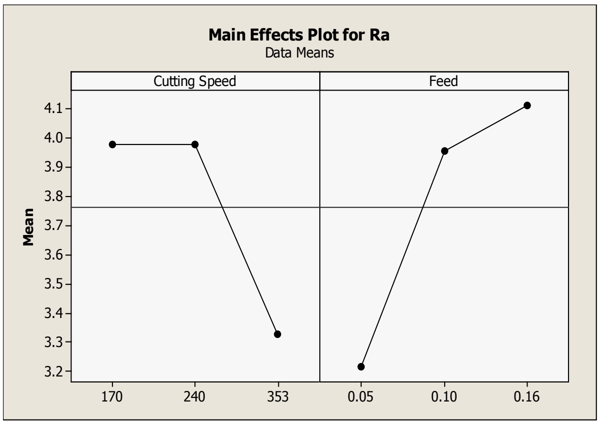

Figure 2 Main effect of surface roughness for coconut wood.

Table 7 Regression analysis: surface roughness values, cutting speed and feed rate for coconut wood.

Regression analysis: R_a versus Cutting speed, Feed rate				
The regression equation is R_a = 3.90 - 0.00375 Cutting speed + 7.93 Feed rate				
Predictor	**Coef**	**SE Coef**	**T**	**P**
Constant	3.8969	0.1203	32.38	0.000
Cutting speed	–0.0037542	0.0003798	–9.88	0.000
Feed rate	7.9313	0.6368	12.45	0.000
S = 0.297604 R^2 = 70.70 % R^2 (adj) = 70.10 %				

Figure 2 shows a tendency indicating that a lower value of feed rate can result in a lower value of surface roughness (R_a) whereas a feed rate at 0.05 mm/rev with a cutting speed at 353 m/min yields the lowest surface roughness (R_a).

The data from **Table 7** can form the relation between the main factors and dependent variables as shown in the following linear equations:

$$R_a = 3.90 - 0.00375 \text{ Cutting speed} + 7.93 \text{ Feed rate} \quad (1)$$

Experiment for result confirmation

An experiment was performed to see if the obtained results were consistent with those of the previous experiments. Linear equations were applied to predict surface roughness values by randomly choosing the cutting conditions as specified. Then the predicted values were compared with the actual values obtained from the experiment with a predicted error of surface roughness. The result from the experiment of mean absolute percentage error (MAPE) of the equation of surface roughness is 4.28 % for coconut wood, which is less than the prediction error value and is acceptable.

Experimental result of palmyra palm wood

Results of sampling sizes

An experiment was performed to find the sampling sizes used statistical values in data analysis. The reliability was at 95 % or a significance of 5 %. The feed rate was at 0.06 mm/rev; the cutting speed was at 267 m/min; the depth of cut was at 1 mm. The twelve repeated treatments revealed that the mean average of surface roughness was at 3.17 µm and the standard deviation was 0.138 µm. Furthermore, the result of the sample size investigation was a 5-sampled size.

The results and result analysis of experiment phase 2

This was to experiment surface roughness affected by the related factors. The completely randomized block design and Minitab R. 15 were applied to calculate statistic values and to analyze the results by Multi Factorial Factors. The statistic values employed were a change rate (F-Ratio) and a reliability value at 95 % with a significance of 5 %. 3 related factors were 2 levels of cutting speed 169 and 240 m/min, 2 levels of feed rate 0.03 and 0.1 mm/rev and 2 levels of depth of cut 0.5 and 2 mm, which resulted in surface roughness values.

The surface roughness values obtained from the planned design indicates R^2 equals 82.44 % and Adjust R^2 was 74.76 %. This means that if variance value of the data is 100 μm^2, the variance value of 82.44 μm^2 can be explained with a regression model, whereas the remaining volume is not explainable due to uncontrollable variables.

Since the values of feed rate and cutting speed can affect variance of the measured data of surface roughness, it can be concluded that the experiment design is accurate and appropriate. Thus, the results of variance can be used in a further analysis. The analyzed results are presented in **Table 8**.

Table 8 and **Figure 3** reveal that the main factors most affecting the surface roughness of palmyra palm wood is cutting speed and feed rate, with a tendency for a higher surface roughness value when feed rate was increased from 0.03 to 0.10 mm/rev. In addition, a greater value of feed rate and a lower cutting speed led to an increase of surface roughness value. The information in **Table 8** shows that no other factors affect the surface roughness.

Table 8 Analyzed results of variance values of surface roughness values for palmyra palm wood.

Analysis of variance for R_a, using Adjusted SS for tests						
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Cutting speed	1	1.22854	1.22854	1.22854	17.94	0.001
Feed rate	1	3.70520	3.70520	3.70520	54.11	0.000
Depth of cut	1	0.07370	0.07370	0.07370	1.08	0.315
Cutting speed*Feed rate	1	0.00000	0.00000	0.00000	0.00	0.994
Cutting speed*Depth of cut	1	0.13054	0.13054	0.13054	1.91	0.186
Feed rate*Depth of cut	1	0.00304	0.00304	0.00304	0.04	0.836
Cutting speed*Feed rate*Depth of cut	1	0.00260	0.00260	0.00260	0.04	0.848
Error	16	1.09567	1.09567	0.06848		
Total	23	9.23930				
S = 0.261685 R^2 = 82.44 % R^2 (adj) = 74.76 %						

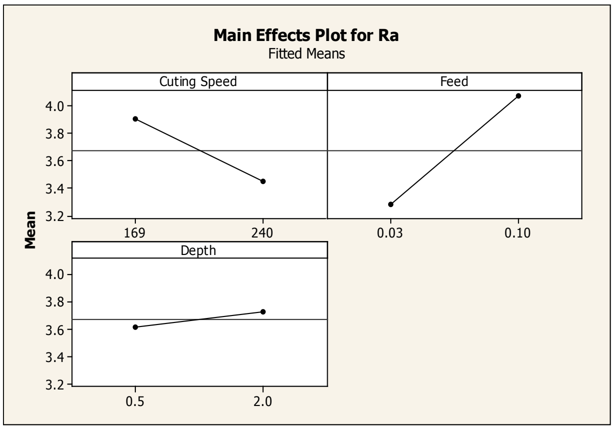

Figure 3 Changes in surface roughness arising from level changes of main factors for palmyra palm wood.

Results and experiment analysis of phase 3

A test was undertaken to adjust variable values to find surface roughness values. The result shows that the main factors affecting surface roughness of palmyra palm wood are feed rate and cutting speed. The result indicates that the decision coefficient (R^2) is 75.97 % and adjust R^2 is 74.02 %. This means that if the variance value of the data is 100 μm^2 the variance value of 75.97 μm^2 can be explained with a regression model, whereas the remaining volume is not explainable due to uncontrollable variables.

Table 9 shows the result from experiment phase 3 concerning surface roughness values, indicating that the main factor most affecting value of surface roughness is feed rate, whereas cutting speed is rated second. Moreover, it was found that the interaction value among the factors has no effect on surface roughness.

Figure 4 shows a tendency indicating that a lower value of feed rate can result in a lower value of surface roughness (R_a) whereas a feed rate at 0.05 mm/rev with a cutting speed at 392 m/min yields the lowest surface roughness (R_a).

Table 9 Analysis of adjusting variable values to find surface roughness values for palmyra palm wood.

Analysis of variance in R_a, using Adjusted SS for tests						
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Cutting speed	2	2.0508	2.0508	1.0254	23.78	0.000
Feed rate	2	11.1688	11.1688	5.5844	129.49	0.000
Cutting speed*Feed rate	4	0.2747	0.2747	0.0687	1.59	0.182
Error	99	4.2694	4.2694	0.0431		
Total	107	17.7636				
S = 0.207665 R^2 = 75.97 % R^2 (adj) = 74.02 %						

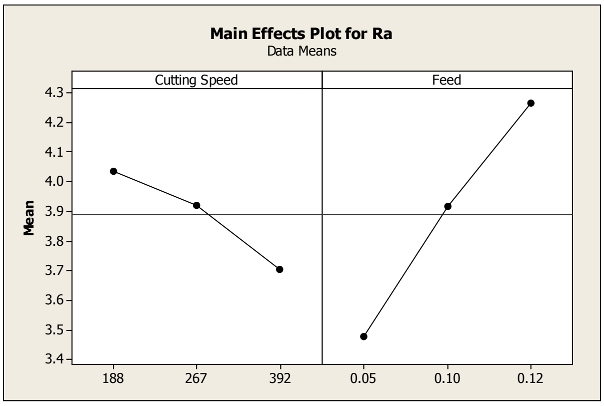

Figure 4 Main effects of surface roughness for palmyra palm wood.

Table 10 Regression analysis: surface roughness values, cutting speed and feed rate for palmyra palm wood.

Regression analysis: R_a versus Cutting speed, Feed rate				
The regression equation is R_a = 3.38 - 0.00164 Cutting speed + 10.80 Feed rate				
Predictor	**Coef**	**SE Coef**	**T**	**P**
Constant	3.38183	0.09653	35.03	0.000
Cutting speed	–0.0016388	0.0002470	–6.63	0.000
Feed rate	10.7596	0.7048	15.27	0.000
S = 0.215619 R^2 = 72.50 % R^2 (adj) = 72.00 %				

The data from **Table 10** can form a relation between the main factors and dependent variables, as shown in the following linear equations:

$$R_a = 3.38 - 0.00164\ \textit{Cutting speed} + 10.80\ \textit{Feed rate} \quad (2)$$

Experiment for result confirmation

An experiment was performed to see if the obtained results were consistent with those of the previous experiments. Linear equations were applied to predict surface roughness values by randomly choosing the cutting conditions as specified. Then the predicted values were compared with the actual values obtained from the experiment with the predicted error of surface roughness. The result from the experiment of mean absolute percentage error of the equation of surface roughness is 3.47 % for palmyra palm wood, which is less than the prediction error value and is acceptable.

Conclusions

The purpose of investigating the surface roughness in the coconut wood and palmyra palm wood turning process using carbide cutting tool blade Plansee Tizit (CERA TIZIT) Model DCGT 11T308FN-27 Grade H10T was to identify the means of the surface roughness of coconut wood and palmyra palm wood turning process, which is a part of furniture manufacture. A completely randomized block factorial design was applied to the research. The main factors, including cutting speed, feed rate and depth of cut, were investigated to find the optimum surface roughness. The following can be concluded;

1) The factor most affecting the surface roughness of coconut wood and palmyra palm wood turning is feed rate, whereas cutting speed also affects it but to a lower extent. The tendency is that a lower feed rate with a higher rate of cutting speed reduces the surface roughness value.

2) The linear equations which resulted from the experiments into coconut wood turning were as follows:

$$R_a = 3.90 - 0.00375\ \textit{Cutting Speed} + 7.93\ \textit{Feed Rate}$$

This equation is applicable to cutting speeds between 170 - 353 m/min, feed rates ranges of 0.05 - 0.16 mm/rev and a depth of cut at 1 mm.

3) When comparing the confirmation treatment from the experiments on the coconut wood turning process and the results by using the referred to formulation, the measurement had an error value of 10 %. The mean absolute percentage error (MAPE) was 4.28 %, which was less than the margin of error and was acceptable.

4) The linear equations which resulted from the experiments into palmyra palm wood turning were as follows:

$$R_a = 3.38 - 0.00164\ \textit{Cutting speed} + 10.80\ \textit{Feed rate}$$

This equation is applicable to cutting speeds between 188 - 392 m/min, feed rates ranges of 0.05 - 0.12 mm/rev and a depth of cut at 1 mm.

5) When comparing the confirmation treatment from the experiments on the palmyra palm wood turning process and the results by using the referred to formulation, the measurement had an error value of 10 %. The mean absolute percentage error (MAPE) was of 3.47 %, which was less than the margin of error and was acceptable.

6) The result also reveals that depth of cut ranges of 0.05 - 2.00 mm. have no effect on the surface roughness of coconut wood and palmyra palm wood.

Acknowledgements

The authors would like to thank the Office of the National Research Council of Thailand for financial support, and also thank the staff of the Automatic Machine Laboratory, Department of Industrial Engineering, Faculty of Engineering, Rajamangala University of Technology Srivijaya, Thailand.

References

[1] S Supadarattanawong and S Rodkwan. An investigation of the optimal cutting conditions in Parawood (Heavea Brasiliensis) machining process on a CNC wood router. *Kasetsart Journal (Natural Science)* 2006; **40**, 311-9.

[2] DA Stephenson and JSA Gapiou. *Metal Cutting Theory and Practice. In*: Taylor & Francis, 2006.

[3] S Rawangwong and J Chatthong. The study of favorable conditions for the cutting text on parawood by computer numerical controlled milling. *In*: IE-Network National Conference, Phuket, Thailand, 2007, p. 121-9.

[4] S Rawangwong and J Chatthong. The study of proper conditions for Palmyra palm wood turning by carbide cutting tool. *In*: IE-Network National Conference, Songkhla, Thailand, 2008, p. 787-95.

[5] S Rawangwong, J Chatthong, P Suwan and J Rodjananugoon. The study of proper conditions for coconut wood turning by carbide cutting tool. *In*: IE-Network National Conference, Khon Kaen, Thailand, 2009, p. 974-82.

[6] S Rawangwong, J Chatthong, J Rodjananugoon and J Jaidumrong. The study of favorable conditions for text engraving on coconut wood using computer numerical controlled milling machine. *In*: IE-Network National Conference, Ubon Ratchathani, Thailand, 2010.

[7] T Arlai, P Kaewtatip and K Prommul. Influences of various working parameter in routing process of rubber wood using tungsten carbide routers. *In*: ME-Network National Conference, Phuket, Thailand, 2003, p. 74-9.

[8] K Prommul, P Kaewtatip and T Arlai. Study on optimum wood cutting condition using PCD. *In*: ME- Network National Conference, Phuket, Thailand, 2002, p. 526-30.

[9] S Rodkwan and JS Strenkowski. A numerical and experimental investigation of the machinability of elastomers. *In*: ME-Network National Conference, Prajinburi, Thailand, 2003.

[10] DC Montgomery. *Design and Analysis of Experiments*. *In*: 6th (ed.). John Wiley & Son, Inc., New York, 2005.