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

S. Rawangwong\textsuperscript{1,*}, J. Chatthong\textsuperscript{1}, J. Rodjananugoon\textsuperscript{1} and W. Boonchouytan\textsuperscript{1}

\textsuperscript{1}Department of Industrial Engineering, Rajamangala University of Technology Srivijaya, Songkhla, 90000, Thailand

Corresponding author; e-mail: sitnong2@yahoo.co.th

Received: xxx, Revised: xxx, Accepted: xxx

Abstract

The purpose of this research is to investigate the effect of main factors on the surface roughness in 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 was between 3.0-9.0 µm before sanding process. The result of preliminary trial shown that the depth of cut had no effect on surface roughness. Moreover, it was found from the experiment that the factors affecting a surface roughness were cutting speed and feed rate, with having 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 $Ra = 3.90 - 0.00375\text{ Cutting Speed} + 7.93\text{ Feed}$. This equation can be best used with 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, and Therefore in the turning process of palmyra palm wood, equation $Ra = 3.38 - 0.00164\text{ Cutting Speed} + 10.8\text{ Feed}$. This equation can be best used with 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 calculate 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 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 [1]. Currently, coconut wood becomes more popular as an important raw material in Thailand furniture manufacturing industry due to unique properties of coconut wood such as beautiful wood pattern, durability and high quality hardwoods. In addition, coconut wood it was found in Southern of Thailand. Consequently, in order to improve the productivity of using coconut wood in furniture manufacturing industry, more understanding of coconut 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. Almost all parts of coconut wood can be useful for daily life of human beings, Its fruits can also be used as main desert ingredients, and its shells as fuel yielding high heat. Moreover, its trunks can be made into wood planks and posts which are resistant to rain, sunlight and friction. The coconut wood is very popular for furniture producing like tables, chairs, sleeping beds, and souvenirs such as motar, wooden plates, spoons, vases, bracelets, candlestick etc. due to its beautiful wood pattern, durability and reasonable price.
Due to its hard wood with grain, the workpiece made of coconut wood often has surface roughness resulted from planning, turning or cutting processes. The workpiece still needs further furnishing leading to a size change in certain part of a furnished workpiece. Several factor affect the surface roughness can be a 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; 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 [3-7]. 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.

The researcher, therefore, is interested in investigating any proper condition in coconut wood and palmyra palm wood turning processes to benefit a coconut wood and palmyra palm wood furniture industry in reduction of time and cost with a better quality product. In addition, the research may be useful for a future research on a similar topic.

**Equipment and Tools**

Equipment and tools employed in the research are:

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

2) Turning machine: Harrison M 300R

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

4) Surface roughness measuring device: Model Mitutoyo Surf Test 301

5) Humidity measuring instrument: Model DT-129

**Methodology**

To find any appropriate conditions in turning coconut wood and palmyra palm wood for furniture producing and other industries, the experiment was divided into 4 phases as the follows:

**Experiment phase 1.** To specify sample sizes for experiment design using Minitab R.15 with statistic reliability and significance at 95% and 5% respectively.

**Experiment phase 2.** A preliminary experiment to identify factors which can be effect surface roughness. A completely randomized block design [8-9] was applied with repetition of 3 times and measuring of 5 times. Minitab R.15 was employed to calculate statistic values and to analyze the multi factors Type 2. The 3 factors and the responsive surface roughness values are shown in Table 1 for coconut wood and Table 2 for palmyra palm wood

<table>
<thead>
<tr>
<th>Factor</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting Speed (m/min)</td>
<td>353</td>
<td>170</td>
</tr>
<tr>
<td>Feed (mm/rev)</td>
<td>0.3</td>
<td>0.05</td>
</tr>
<tr>
<td>Depth of cut (mm)</td>
<td>2</td>
<td>0.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factor</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting Speed (m/min)</td>
<td>240</td>
<td>169</td>
</tr>
<tr>
<td>Feed (mm/rev)</td>
<td>0.1</td>
<td>0.03</td>
</tr>
<tr>
<td>Depth of cut (mm)</td>
<td>2</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Experiment phase 3. To adjust the variable values to specify roughness values. General factorial design was utilized to adjust variable values to see responsive effect. In the experiment includes 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 effect to roughness as shown in Table 3. To reduce variance leading to higher reliability, the experiment of this phase was carried out in 12 times and measured in 5 times and Table 4 for palmyra palm wood

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Specification of variables in experiment phase 3 for coconut wood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>Level 1</td>
</tr>
<tr>
<td>Cutting Speed (m/min)</td>
<td>170</td>
</tr>
<tr>
<td>Feed (mm/rev)</td>
<td>0.05</td>
</tr>
<tr>
<td>Depth of cut (mm)</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Specification of variables in experiment phase 3 for palmyra palm wood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>Level 1</td>
</tr>
<tr>
<td>Cutting Speed (m/min)</td>
<td>188</td>
</tr>
<tr>
<td>Feed (mm/rev)</td>
<td>0.05</td>
</tr>
<tr>
<td>Depth of cut (mm)</td>
<td>1</td>
</tr>
</tbody>
</table>

Experiment phase 4. This experiment was undertaken for consistent result confirmation. The linear equation obtained in experiment phase 3 was used to predict the randomized turning conditions. 6 cutting conditions were randomly selected with 5 tests of repetition with margin error not over 10%.

Experimental result of coconut wood

1. Results of sampling sizes. The statistic values used in data analysis were reliability at 95% or significance at 5% and S.D. value of 0.382 µm. The S.D. value was obtained from data collection of cutting speed at 240 m/min, feed rate at 0.1 mm/rev and a depth of cut at 1 mm with 12 rounds of turning conditions including 4-12 sample sizes. The mean of surface roughness was 3.331 µm.

2. 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 reliability value at 95% with significance of 5%.

The surface roughness values obtained from the planned design indicates $R^2$ equals 88.70% and Adjust $R^2$ was 83.75%. This means that if variance value of the data is 100 µm², the variance value of 88.70 µm² 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 Fig. 1.

Fig. 1 and Fig. 2 reveal that the main factor effected the surface roughness of coconut wood is cutting speed and feed rate with tendency of higher surface roughness value when a feed rate was increased from 0.05 mm/rev 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 Fig. 1 shows that no other factors affect the surface roughness.
3. Results and experiment analysis phase 3. The 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%. The mean that if variance value of the data is 100 $\mu m^2$ the variance value of 87.19 $\mu m^2$ can be explained with a regression model whereas the remaining volume is not explainable due to uncontrollable variables.
Fig. 3 Analysis of adjusting variable values to find surface roughness values

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

Fig. 4 Main effect of surface roughness

Fig. 4 shows a tendency indicating that a lower value of feed rate can result in a lower value of $R_a$ whereas a feed rate at 0.05 mm/rev with cutting speed at 353 m/min yields the lowest $R_a$.

Regression Analysis: $R_a$ versus Cutting Speed, Feed

The regression equation is

$$R_a = 3.90 - 0.00375 \times \text{Cutting Speed} + 7.93 \times \text{Feed}$$

Fig. 5 Regression analysis: surface roughness values, cutting speed and feed rate
The data from Fig. 5 can form the relation between the main factors and dependent variables as shown in the following linear equations:

\[ Ra = 3.90 - 0.00375 \text{ Cutting Speed} + 7.93 \text{ Feed} \] (1)

4. Experiment for result confirmation. The experiment was performed to see if the obtained results were in consistency with those of the past experiments. The 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 (MAPE) of the equation of surface roughness is 4.28% for coconut wood, which is less than prediction error value and is acceptable.

Experimental result of palmyra palm wood

1. Results of sampling sizes. The statistic values used in data analysis were reliability at 95% or significance at 5% and S.D. value of 0.138 µm. The S.D. value was obtained from data collection of cutting speed at 267 m/min, feed rate at 0.06 mm/rev and a depth of cut at 1 mm with 12 rounds of turning conditions including 3-10 sample sizes. The mean of surface roughness was 3.17 µm.

2. 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 reliability value at 95% with significance of 5%. 3 related factors were 2 levels of cutting speed 169 and 240 m/minute, 2 levels of feed rate 0.03 and 0.1 mm/rev and 2 levels of turning depth of cut 0.5 and 2 mm, which resulted in surface roughness values.

The surface roughness values obtained from the planned design indicates R² equals 82.44% and Adjust R² was 74.76%. This means that if variance of the data is 100 µm², the variance value of 82.44 µm² 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 Fig. 6.

Fig. 6 and Fig. 7 reveal that the main factor effected the surface roughness of palmyra palm wood is a cutting speed and feed rate with tendency of higher surface roughness value when a feed rate was increased from 0.03 mm/rev 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 Fig. 7 shows that no other factors affect the surface roughness.

Analysis of Variance for Ra, using Adjusted SS for Tests

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting Speed</td>
<td>1</td>
<td>1.22854</td>
<td>1.22854</td>
<td>1.22854</td>
<td>17.94</td>
<td>0.001</td>
</tr>
<tr>
<td>Feed</td>
<td>1</td>
<td>0.70520</td>
<td>0.70520</td>
<td>0.70520</td>
<td>54.11</td>
<td>0.000</td>
</tr>
<tr>
<td>Depth</td>
<td>1</td>
<td>0.07370</td>
<td>0.07370</td>
<td>0.07370</td>
<td>1.08</td>
<td>0.315</td>
</tr>
<tr>
<td>Cutting Speed*Feed</td>
<td>1</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00000</td>
<td>0.00</td>
<td>0.944</td>
</tr>
<tr>
<td>Cutting Speed*Depth</td>
<td>1</td>
<td>0.13054</td>
<td>0.13054</td>
<td>0.13054</td>
<td>1.91</td>
<td>0.186</td>
</tr>
<tr>
<td>Feed*Depth</td>
<td>1</td>
<td>0.00304</td>
<td>0.00304</td>
<td>0.00304</td>
<td>0.04</td>
<td>0.836</td>
</tr>
<tr>
<td>Cutting Speed<em>Feed</em>Depth</td>
<td>1</td>
<td>0.00260</td>
<td>0.00260</td>
<td>0.00260</td>
<td>0.04</td>
<td>0.648</td>
</tr>
<tr>
<td>Error</td>
<td>15</td>
<td>1.09567</td>
<td>1.09567</td>
<td>0.06971</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
<td>6.33630</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S = 0.261685 \quad R-Sq = 82.44% \quad R-Sq(adj) = 74.76%

Fig. 6 Analyzed results of variance values of surface roughness values
3. Results and experiment analysis phase 3. The 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 a feed rate and cutting speed. The result indicates that the decision coefficient (R²) is 82.44% and adjust R² was 74.76%. The mean that if variance value of the data is 100 µm² the variance value of 82.44 µm² can be explained with a regression model whereas the remaining volume is not explainable due to uncontrollable variables.

Fig. 8 shows the result from experiment phase 3 concerning surface roughness values indicating that the main factor most effecting value of surface roughness is a feed rate whereas a cutting speed is rated in the second. Moreover, it was found that the interaction value among the factors has no effect on surface roughness.

Analysis of Variance for Ra, using Adjusted SS for Tests

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting Speed</td>
<td>2</td>
<td>2.0508</td>
<td>2.0508</td>
<td>1.0254</td>
<td>23.78</td>
<td>0.000</td>
</tr>
<tr>
<td>Feed</td>
<td>2</td>
<td>11.1560</td>
<td>11.1338</td>
<td>5.5694</td>
<td>153.49</td>
<td>0.000</td>
</tr>
<tr>
<td>Cutting Speed*Feed</td>
<td>4</td>
<td>0.2747</td>
<td>0.2747</td>
<td>0.0687</td>
<td>1.59</td>
<td>0.152</td>
</tr>
<tr>
<td>Error</td>
<td>99</td>
<td>4.2454</td>
<td>4.2454</td>
<td>0.0431</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>107</td>
<td>17.6636</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$S = 0.207665 \quad R-Sq = 75.97\% \quad R-Sq(adj) = 74.02\%$

Fig. 8 Analysis of adjusting variable values to find surface roughness values

Fig. 9 shows a tendency indicating that a lower value of feed rate can result in a lower value of Ra whereas a feed rate at 0.05 mm/rev with cutting speed at 392 m/min yields the lowest Ra.
Fig. 9 Main effects of surface roughness

Regression Analysis: Ra versus Cutting Speed, Feed

The regression equation is

\[
Ra = 3.38 - 0.00164 \text{ Cutting Speed} + 10.8 \text{ Feed}
\] (2)

4. Experiment for result confirmation. The experiment was performed to see if the obtained results were in consistency with those of the past experiments. The 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 prediction error value and is acceptable.

Conclusion

The study on turning coconut wood and palmyra palm wood utilizing a carbide cutting tool blade Plansee Tizit (CERA TIZIT) Model DCGT 11T308FN-27 Grade H10T is to examine its surface roughness values in furniture producing. The assumed affecting factors were cutting speed, feed rate and depth of cut whereas completely randomized block design was applied in the research. The targets of the study were to examine the effects in surface roughness. The results of the study can be summarized as the follows:
1) The factor most affects the surface roughness of coconut wood and palmyra palm wood turning is a feed rate whereas a cutting speed also affects it but in a lower extent. The tendency is that a lower rate of feeding with a higher rate of cutting speed reduces a surface roughness value.

2) The linear equations resulted from the experiments coconut wood turning are as follows:

$$Ra = 3.90 - 0.00375 \text{ Cutting Speed} + 7.93 \text{ Feed}$$

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) The linear equations resulted from the experiments palmyra palm wood turning are as follows:

$$Ra = 3.38 - 0.00164 \text{ Cutting Speed} + 10.8 \text{ Feed}$$

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.

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

**Acknowledgments**

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

**References**


