

Cutter usage management for rubberwood furniture part machining process

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Abstract

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The objective of this research work was to improve cutter usage management of a vertical-shaft cutting machine for rubberwood furniture industry. The milling cutter used consists of six-straight teeth mounted on the vertical-shaft of a milling machine. A pre-cut rubberwood specimen had the height of 40 mm and outer curve length of 330 mm. The steps of study were (1) studying the current cutter usage management of a factory through studying the important factors of current manually cutting such as specimen feed, cut depth, and cutting speed. (2) Developing the process for improvement of cutter usage management via studying sanding time and roughness after sanding with the coarse and fine size grits of sand paper number 100 and 180, respectively which the furniture factories normally apply; setting-up the surface roughness requirement for a cut-part application; studying a suitable cutting condition for part machining by controlling the cutting factors, and also determining the tool life that provided the cut-surface roughness equivalent to the roughness sanded by the sand paper number 100; and finally, developing the method for improvement.

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The study found that (1) the specimen feed had a significant effect on tool life. The higher feed caused a decreased tool life and an increased cut surface roughness; (2) the cutter was used to cut the specimen until the cut surface of specimen was torn grain or specimen could not be machined. Consequently, all the cut specimens had to be sanded by coarse and fine sanding, and the total time was 16.2 sec/piece; and (3) the method developed was setting the tool life which was equal to the accumulated machining time performing the cut-surface roughness of $8 \mu\text{m}$ equivalent to the roughness sanded by using the size grit number of 100. It could eliminate coarse sanding operation. Therefore, the total sanding time remarkably decreased from the existing 16.2 sec/piece to 6.1 sec/piece or 62.2 % reduction of existing time.

Key words : cutter usage, management, machining process, rubberwood furniture

บทคัดย่อ

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การจัดการการใช้ใบมีดสำหรับกระบวนการตัดชิ้นรูปชิ้นงานเฟอร์นิเจอร์จากไม้ยางพารา
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งานวิจัยนี้มีวัตถุประสงค์เพื่อปรับปรุงวิธีการจัดการการใช้ใบมีดตัดของเครื่องตัดแบบเพลที่ตั้งใช้ในโรงงานผลิตเฟอร์นิเจอร์ไม้ยางพารา โดยใบมีดตัดที่ใช้ในการศึกษานี้ เป็นชุดหัวตัดชนิดฟันตรงซึ่งใช้กับเครื่องตัดแบบเพลตั้ง ชุดใบมีดประกอบด้วยใบตัดจำนวน 6 ใบ และเป็นวัสดุชนิดเหล็กกล้าคาร์ไบด์ เกรด K20 ชิ้นงานไม้ยางพาราก่อนตัดมีขนาดความสูงและความยาวโค้งด้านนอกซึ่งเป็นด้านที่ต้องการตัดเท่ากับ 40 มม. และ 330 มม. ตามลำดับ การศึกษาเริ่มจาก (1) ศึกษาการจัดการการใช้ใบมีดตัดของโรงงานในปัจจุบัน โดยศึกษาปัจจัยที่เป็นตัวแปรสำคัญของการตัดโดยพนักงานที่ใช้ในปัจจุบัน ได้แก่ อัตราการป้อนชิ้นงาน ระยะลึกของรอยตัด และความเร็วตัด (2) พัฒนาระบบการปรับปรุงสำหรับการจัดการการใช้ใบมีดตัด โดยศึกษาเวลาและความหยาบผิวของชิ้นงานตัดที่ผ่านการขัดหยาบและขัดละเอียดด้วยเครื่องขัดกระดาษทรายเบอร์ 100 และ 180 ซึ่งปัจจุบันโรงงานทั่วไปใช้อยู่ กำหนดระดับความหยาบผิวของชิ้นงานที่โรงงานต้องการ ศึกษาปัจจัยการตัดที่เหมาะสมสำหรับการตัดชิ้นรูปชิ้นงาน โดยควบคุมปัจจัยการตัดให้คงที่ และหาอายุการใช้งานของใบมีดตัดโดยพิจารณาความหยาบผิวเท่ากับผลการขัดกระดาษทรายเบอร์ 100 และสุดท้าย กำหนดมาตรการสำหรับการจัดการการใช้ใบมีดตัด และ (3) นำมาตรการที่พัฒนาขึ้นไปทดลองปฏิบัติและเปรียบเทียบผล

จากการศึกษาพบว่า (1) อัตราการป้อนชิ้นงานเข้าเครื่องเพลที่ตั้ง จะมีอิทธิพลอย่างมากต่ออายุการใช้งานของใบมีด อัตราป้อนชิ้นงานที่สูงขึ้นมีผลให้อายุใบมีดตัดลดลงและค่าความหยาบผิวของชิ้นงานตัดเพิ่มขึ้น (2) พนักงานจะใช้ใบมีดตัดจนผิวชิ้นงานตัดเกิดเสี้ยนหรือใบมีดนั้นไม่สามารถตัดชิ้นงานต่อไปได้ และชิ้นงานตัดทุกชิ้นต้องผ่านขั้นตอนการขัดหยาบและขัดละเอียด ตามลำดับ ทำให้ใช้เวลาขัดต่อชิ้นรวม 16.2 วินาที (3) มาตรการที่ถูกพัฒนาขึ้นคือ การกำหนดให้อายุใบมีดตัดเท่ากับระยะเวลาการตัดสะสมที่ทำให้ชิ้นงานตัดมีความหยาบผิวเท่ากับ $8 \mu\text{m}$ ซึ่งเท่ากับความหยาบผิวหลังการขัดด้วยเครื่องขัดกระดาษทรายเบอร์ 100 นั้น จะทำให้ลดขั้นตอนการขัดหยาบและเวลาการขัดผิวลงจากเดิม 16.2 วินาที/ชิ้นงานขัด เป็น 6.1 วินาที/ชิ้นงานขัด หรือลดลงจากเดิมคิดเป็น 62%

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The export of furniture from Thailand is dominated by wooden products, which comprise over 70% of the total export figure, with metal furniture being the second largest product in the

category registering just over 10%. Wooden furniture manufacturers have adapted well to the shift to rubber wood and currently use it in 60% of production and 80% of wooden furniture exports

(Thai Portal Co., Ltd., 2005). Rubberwood and labor are mainly domestic resources for supporting this industry. Rubberwood used for producing furniture was prepared from rubber trees by cutting off. The timber cut was transformed to lumber, and then chemically treated and kiln dried. The lumber was machined to form a furniture part generally using a vertical milling machine. The cut part, in particular the part for surface finishing, will be ground using sanding machine with sand paper number 100 and then number 180 which are common applied in the industry. Figure 1 shows a basic diagram of furniture part forming. The major problem of machining process for this industry is that of cutter usage management. The milling cutter is used till the surface of cut-part became torn grain and sometimes damaged. The staffs have never been concerned about a suitable tool life of the cutter for reducing sanding time when the sanding process is preceded by the milling machine. Currently, the cut-surface roughness after machining and each sanding machines is not determined, and therefore the sanding process is a unit that needs more workers and time to finish the final roughness. Besides, the distinct problem is dust mainly generated from sanding process. Therefore, the research objective was to (1) improve the

current method of cutter usage management of a vertical milling machine for rubberwood furniture industry, (2) determine a suitable cutting condition and tool life for reducing sanding time.

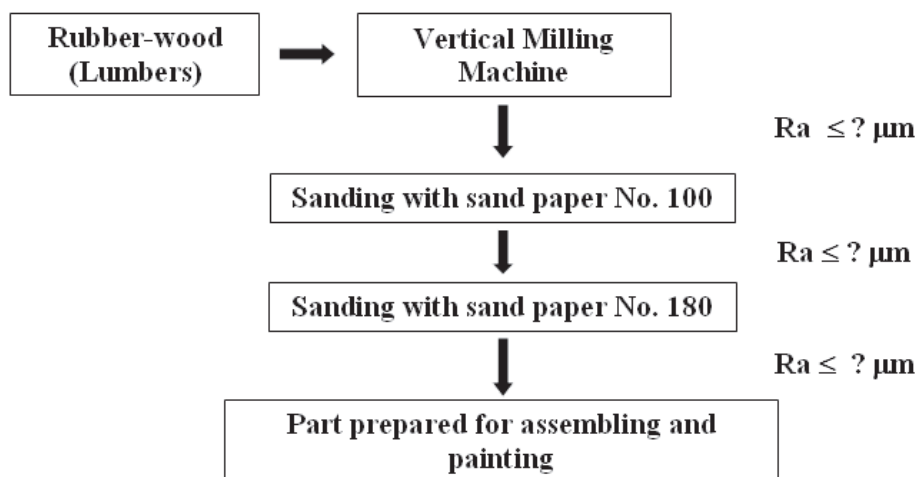
Materials and Method

P.P. Parawood Co., Ltd., a Para-wood furniture manufacturer, is located at Ampour Panusnikom, Chonburi province, provided the facilities and resources for this research.

1. Materials and Equipments

Precut rubberwood specimens having the height of 40 mm, the outer curve length (*l*) of 330 mm, inner curve radius of 455 mm. (R455), and the width of over than 45 mm. were studied. The moisture and density of the specimens were $9.4 \pm 0.5 \%$ and $0.61 \pm 0.3 \text{ Mg/m}^3$, respectively. Figure 2 shows the dimension of the work-piece required after machining.

The main equipment used in this study were a vertical milling machine and a plain six-tooth cutter having as shown in Figure 3 and Figure 4, respectively. The vertical milling machine has a table length of 1.25 m., a velocity of the table-move up to 8.33 m/min., and shaft revolution from



Remark: "Ra" is the surface roughness after machining process
 "?" is unknown roughness after machining process

Figure 1. Simple flow diagram of furniture part forming process.

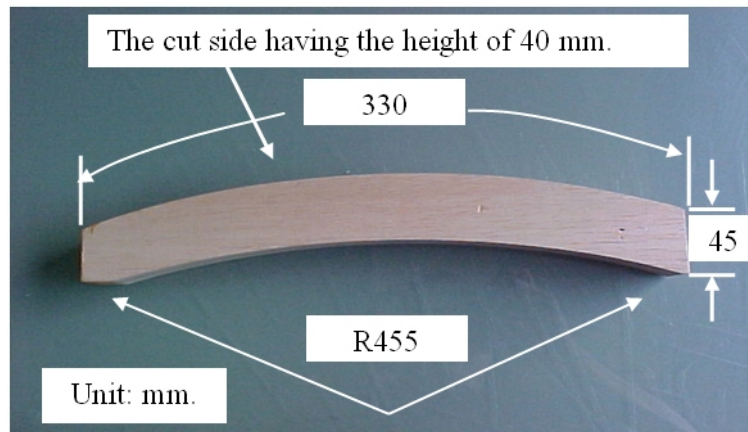


Figure 2. Dimensions of a work-piece required after machining.

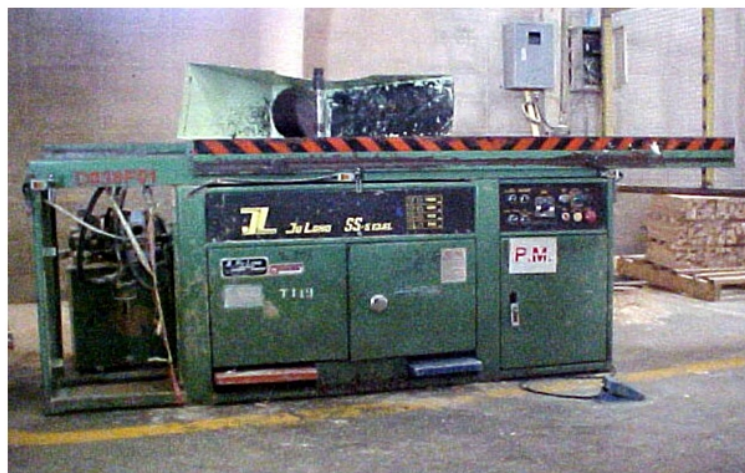


Figure 3. The vertical milling machine employed in this study.

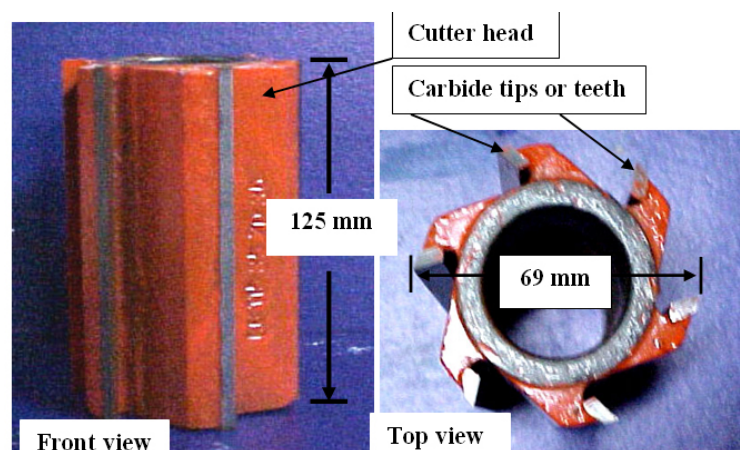


Figure 4. Front and Top views of a six-tooth milling cutter used in this study.

3,500 to 8,000 rpm. The teeth of the cutters used were tungsten carbide steel with grade number of K20, having tool angel of $52.6 \pm 1.6^\circ$, and the cutter height of 125 mm. Six blades were fixed on a cutter-head which had a diameter (D) of 69 mm. A simple diagram of milling process of this study was shown in Figure 5. A work-piece was fed through the milling cutter rotating. The variables of cutter revolution (N), work-piece feed (f), and cut depth (d) were studied investigating effects on the cut surface roughness and tool wear (the land width of cutting edge, L) as shown in Figure 6.

Instruments and devices used in tool life analysis were roughness tester of Mitutoyo model MST 301, scanning electron microscope (SEM) of JEOL model JSM-5800 LV, and revolution tester Pantec model DTM 30.

2. Method

Steps of the study were as follows:

2.1 Studying the existing cutter usage management

The factory's machining process operation was observed such as cutter usage manage-

ment and cutting conditions (depth of cut, cutting speed, and specimen feed) surface roughness of the cut part was considered to determine tool life and tool wear.

2.2 Developing the process for improvement of cutter usage management

The process improvement for cutter usage management was as follows:

1) Study of sanding time and roughness cut-part after sanding process

The sequence of machined work-piece was sanded with the size grits of sand paper numbers 100 and then number 180 using sanding machines. Sanding time and surface roughness after sanding of each process were determined.

2) Set-up of the surface roughness requirement for furniture components

The customer requirements of surface roughness of furniture component were firstly considered. The manufacturing specifications of furniture component types which were machined within the factory were then set-up by brain-storming meeting between departmental managers and engineers who were concerned.

N = Revolution of cutter (rpm), f = feed (m/min), and d = depth of cut

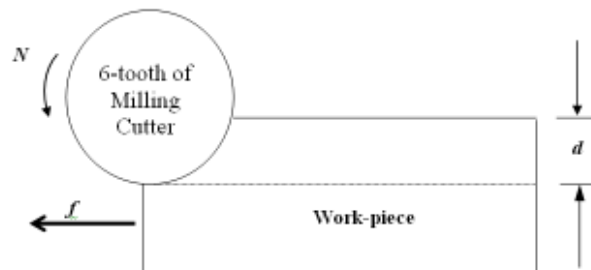


Figure 5. Simple diagram of vertical milling process (Top view).

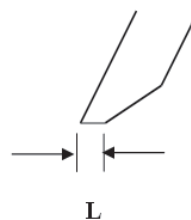


Figure 6. The land width (L) of cutting edge.

3) Study of the effect of the cutting conditions on cut-surface roughness and tool wear

The machining condition factors affecting tool life were revolution per minute (N : rpm) or cutting speed (v), feed of the specimen (f), and depth of cut (d). The machining control condition is that of controlling constant feed using hydraulic device, cut depth and cutting speed. The experimental plan lay-out of machining control condition was shown in Table 1. A factor was varied, whereas the other two factors were fixed. The revolutions (N) of milling cutter having 69 mm in diameter (D) were varied from 3755, 4900, and 7900 rpm. The cutting speeds (v) converted by the equation (1) were then 814, 1062, and 1712 m/min, respectively. Specimen feed was a function of feed per tooth (f_n), number of teeth (n), and revolution of milling cutter (N) as shown in the equation (2). Machining time per specimen (t) could be determined by curve length (l) of 330 mm as equation (3). (El Wakil, 2002)

$$v = \pi \times D \times 10^3 \times N \tag{1}$$

$$f = f_n \times n \times N \tag{2}$$

$$t = \frac{l}{1000 \times f} \tag{3}$$

The constant feeds of specimens (f) were controlled using hydraulic device, and also were varied from 3, 5 and 7 m/min. The cut depths of specimens were set as 3, 5 and 7 mm. respectively. The land width of cutting edge before and

after machining was determined using the SEM. A random cut-surface roughness of work pieces after machining was measured consecutive in every the 50th of cut specimens. A land width of cutting edge (L) during a starting and the end of machining was observed using the SEM.

The relation of response variables, such as surface roughness, tool life, and average land width of cutting edge, and independent variables were analyzed by statistical regression technique using Microsoft Excel program.

4) Development of the method for improvement of cutter usage management

A method for cutter usage management improvement was created by analyzing the results of the 2.1 to 2.2.

2.3 Implementing the process developed and comparing the results

The best cutting condition, obtained by the experiment, and the method of cutter usage management improvement created were implemented to the production line of the part machining process in order to compare with the existing process.

Results and Discussion

1. The current cutter usage management

The vertical milling machine was operated by his operator. Cutting conditions observed were cutter revolution, depth of cut, and specimen feed. The cutter revolution or cutting speed was operated at 7900 rpm or 1712 m/min respectively.

Table 1. Experimental plan lay-out for control of cutting conditions.

Specimen feed (f) m/min	Cutting speed (V); m/min or [Revolution (N); rpm]					
	814 or [3,755]		1,062 or [4,900]		1,712 or [7,900]	
	Depth of cut (d); mm.					
	3	5	3	5	3	5
3	X	X	X	X	X	X
5	X	X	X	X	X	X
7	X	X	X	X	X	X

Remark: x is response variables; such as Cut-surface roughness and average land width of cutting edge

The depth of cut of each specimen was prepared with the range between 2.7 ± 0.7 and 4.1 ± 0.8 mm. The velocity of the specimen manually fed was inconsistent with the range of 6.4 ± 1.0 and 10.7 ± 1.7 m/min. The cutter applied to pre-form cutting part was used until the cut-part surface become torn grain or the cutting edge of the cutter worn out. The attitude of the machining operator was that the cut-part surface could be corrected by sanding process and the sanding time was out of concern.

Table 2 shows the result of tool life and tool wear obtained from the existing condition. Figure 7 shows the relation of cut-specimen quantity and cut-surface roughness of as-received, as the 1st round of grinding, and as the 2nd round of grinding.

The as-received cutter supplied by a local tool maker provided the cut-part quantity of 390 pieces, and also tool life of 12.0 min. and tool wear rate of $0.47 \mu\text{m}/\text{min}$, whereas, the 1st and the 2nd round of ground cutters provided greater cut-part quantity and longer tool life the as-received cutter. Figure 8 and Figure 9 show the land width of the cutting edge for the as-received cutter and ground-edge cutter as-started and as-finished production. The land width of as-received cutter was approximately $20 \mu\text{m}$. The ground-edge cutter as-started had the land width of $10 \mu\text{m}$, whilst the after finishing production, the land width became $30 \mu\text{m}$.

Table 2. Result of tool life and tool wear for the existing cutting conditions.

Cutter No.	Number of grinding	Cutting Condition			Cut part quantity (Part) (1)	Tool life (Min) (2)	Increased roughness (μm)(3)	Tool wear rate	
		f (m/min)	d (mm.)	v (m/min)				$\mu\text{m}/\text{Min}$ (3)/(2)	$\mu\text{m}/\text{Part}$ (3)/(1)
1	As-received	10.7 ± 1.7	3.4 ± 0.9	1712	560	17.2	8.1	0.47	0.014
	1	6.4 ± 1.0	3.5 ± 0.9	1712	600	30.0	5.5	0.18	0.009
	2	6.8 ± 1.1	2.9 ± 0.8	1712	700	34.0	7.7	0.23	0.011
2	As-received	6.4 ± 0.9	3.7 ± 0.8	1712	N/A	N/A	7.2	N/A	N/A
	1	6.7 ± 1.0	4.1 ± 0.8	1712	600	29.4	7.2	0.25	0.012
	2	7.2 ± 1.0	2.7 ± 0.7	1712	650	30.0	7.5	0.25	0.011

Remark: N/A = could not be machined due to tool worn.

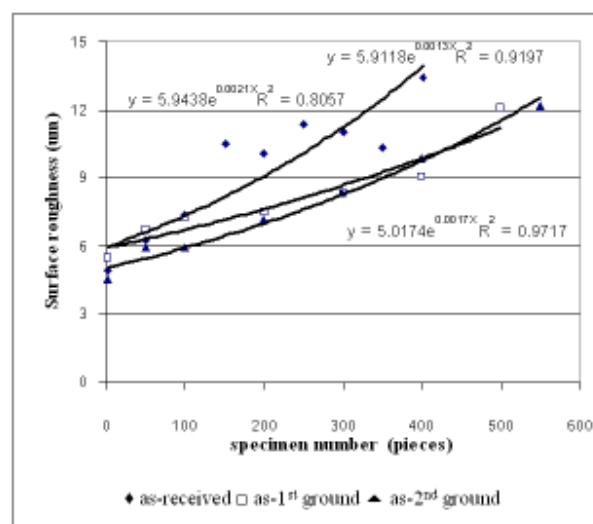


Figure 7. The surface roughness versus specimens cut by as-received cutter, as-the 1st ground, and as-the 2nd ground cutters.

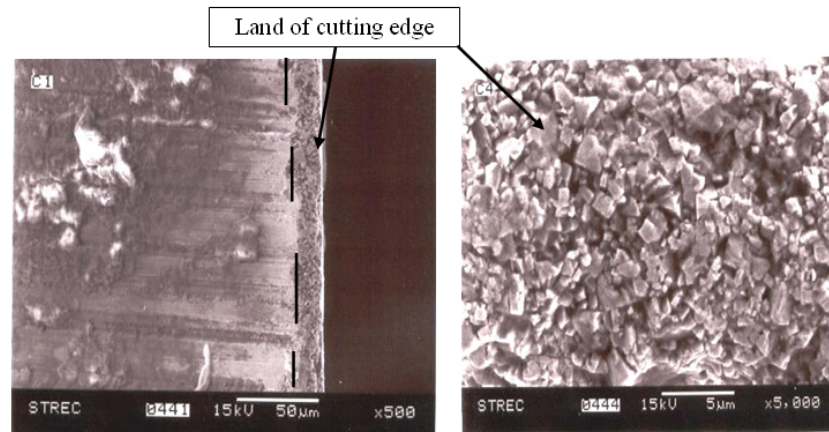


Figure 8. The land of cutting edge of as-received cutter supplied from tool-manufacturer observed by SEM using magnification of 500 and 5,000 times.

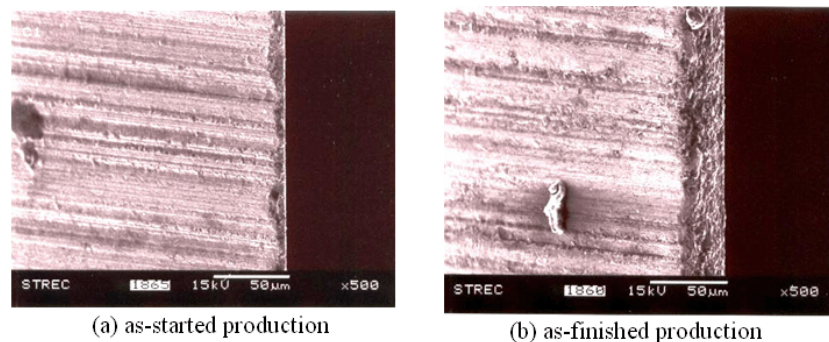


Figure 9. The SEM of the land width of a ground-edge of cutter as-started and as-finished part production.

2. The development of the process improvement

Ground-surface roughness and sanding time for the sand paper number of 100 were $8.1 \pm 0.8 \mu\text{m}$ and $10.1 \pm 1.7 \text{ min}$, respectively, and for the sand paper number 180 $6.6 \pm 1.2 \mu\text{m}$ and $3.8 \pm 0.8 \text{ min}$, respectively, as shown in Table 3.

The ranges of cut-surface roughness requirement for the types of the furniture part are shown in Table 4. The cut-part roughness for the surface finishing should not be more than $5 \mu\text{m}$, which was more than the ground-surface roughness after sanding with the sand paper number 180. Therefore, all the cut-part for surface finishing had to be final sanded by the paper of 180.

Figure 10 and Figure 11 show the results of the experimental cutting condition with respect to

the cut-depth (d) of 3 mm. and the cutter revolution (N) of 7900 rpm with the specimen feed (f) varied to 3, 5, and 7 m/min. The cut-surface roughness increased with increasing machining time for all conditions. With the cut-depth and cutter revolution kept constant at 3 mm and 7900 rpm, respectively, tool life increased with the decreasing of the specimen feed. The feed (f) of 3 m/min provided the longest tool life and least tool wear.

Figure 12 and Figure 13 showed that the specimen feed had remarkable effects on tool life and tool-wear rate.

Figure 14 indicates the redundant sanding of the cut-specimen for the existing cutter usage management. All of the specimen machined were sanded with the sand paper no. 100 giving the

Table 3. Average surface roughness and sanding time results from 20 machined parts after sanding with sand paper no. 100 and 180.

Items	Starting roughness	Sanding with paper no. 100			Sanding with paper no. 180			Total time per part (Sec)
		Ra after sanding (μm)	Sanding time per part (Sec)	Ra* ¹ decreased (μm)	Ra after sanding (μm)	Sanding time per part (Sec)	Ra* ¹ decreased (μm)	
Maximum	10.1	9.7	14.5	0.4	4.7	10.5	5.4	25.0
Minimum	4.5	6.6	7.7	(2.1)* ²	3.7	5.3	0.8	13.0
Average	6.9 \pm 1.4	8.1 \pm 0.8	10.1 \pm 1.7	(1.2 \pm 1.7)* ²	4.2 \pm 0.3	6.6 \pm 1.2	3.8 \pm 0.8	16.7 \pm 2.3

Remark: *1 Roughness after sanding was different from the starting roughness being the cut part roughness.

*2 Roughness increased.

Table 4. Interval cut-surface roughness requirement of the types of furniture parts.

Level number	Interval roughness requirement (Ra; mm)	Types of machined part Application
1	$9 \leq Ra \leq 12$	Parts for leather-sheet covered
2	$9 \leq Ra \leq 11$	Pre-form parts
3	$8 \leq Ra \leq 10$	Parts for tri-angle sanding
4	$7 \leq Ra \leq 9$	Parts for tri-angle sanding
5	$Ra \leq 5$	Parts for surface finishing

roughness of $8.08 \pm 0.8 \mu\text{m}$, and then followed by the sand paper no. 180 giving the roughness of $4.2 \pm 0.8 \mu\text{m}$, whereas the 1st to the 200th cut-specimen had a surface roughness less than $8 \mu\text{m}$ were also sanded with the paper no. 100.

Table 5 shows the comparative results of tool life and tool wear when the specimens were fed by the manual and hydraulic feeder and the roughness was considered at $8 \mu\text{m}$. The tool life and tool-wear rate of the cutter which was applied by manual feed of specimen could be worse than the cutter which was performed by controlled feed of specimen. The tool life and tool-wear rate of the cutter were 13.30 min and $0.23 \mu\text{m}/\text{min}$, respectively.

Figure 15 demonstrates the flow diagram of the cutter usage management method. The method criterion was that the cutter was applied to cut the specimen until the surface roughness of the cut-past was equal or less than $8 \mu\text{m}$, then the cutter was considered to (1) retreat the cutting-edge or

(2) cut the other part requiring the roughness more than $8 \mu\text{m}$.

3. The comparison of the implementation results

Figure 16 shows the relation of the cut-surface roughness and cut-part quantity of the specimen-feed methods between manual and hydraulic with the cutter revolution (N) and cut-depth (d) controlled at 7900 rpm and 3 mm, respectively. The hydraulic feeder set at 3 m/min provided the tool life of 27.88 minute whilst the manual feed being the average of 4.1 ± 0.9 m/min gave the tool life of 16.44 minute, when the cut-surface roughness condition for tool life consideration was $8 \mu\text{m}$ as shown in the Table 6.

Figure 17 shows the tool life and cut-part quantity with respect to $8 \mu\text{m}$ of cut-surface roughness plotted against specimen feed when the cut-depth and cutter-revolution were controlled at 3 mm. and 7900 rpm, respectively, quoted from the studied results. The relationship between the

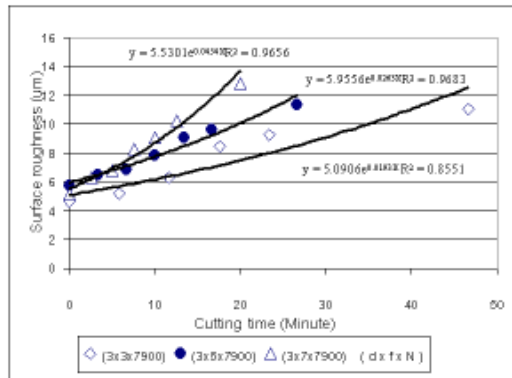


Figure 10. Surface roughness and cutting time varied with controlled feeds of 3, 5, 7 m/min whereas the cut depth and revolution were fixed at 3 mm. and 7900 rpm, respectively.

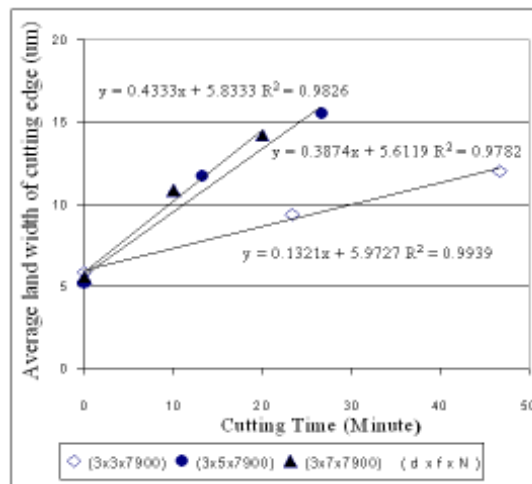


Figure 11. Average land width (L) and cutting time varied with controlled feeds of 3, 5, 7 m/min whereas the cut depth and revolution were fixed at 3 mm. and 7900 rpm, respectively.

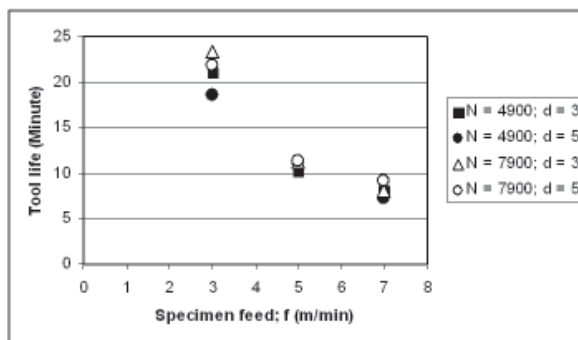


Figure 12. Tool life versus specimen feed (f) with respected to revolution (N) and cut depth (d) when surface roughness of $8 \mu\text{m}$ was the condition.

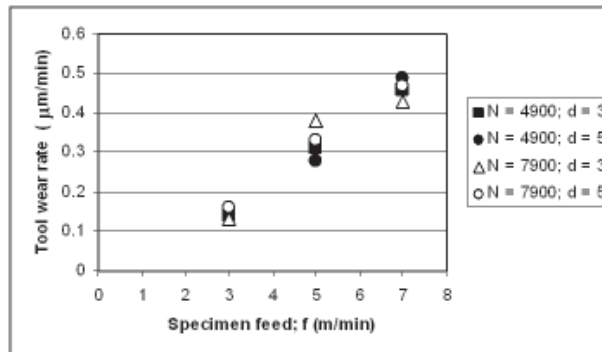


Figure 13. Tool wear rate ($\Delta L/\text{min}$) versus specimen feed (f) with respected to revolution (N) and cut depth (d) when surface roughness of $8 \mu\text{m}$ was the condition

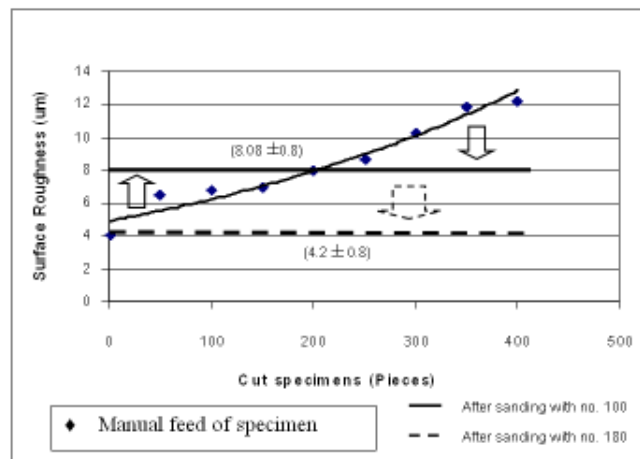


Figure 14. The surface roughness of each specimen cut by manual feed after sanding with the sand paper no. 100 and 180.

Table 5. Comparative results between manual and controlled condition when 8 mm of surface roughness was set as a tool life condition.

Items	Units	Existing* ¹ (1)	Controlled condition* ² (2)	Different (%) $\frac{(2)-(1)}{(1)} \times 100$	Remarks
1. Tool life	Minute	13.30	23.4	43.1	Increased
2. Cut part quantity	Piece	275	209	(31.6)	Decreased
3. Tool wear ratio with respect to tool life	$\mu\text{m}/\text{minute}$	0.23	0.13	(76.9)	Decreased
4. Tool wear ratio with respect to cut part quantity	$\mu\text{m}/\text{piece}$	0.011	0.014	21.43	Increased

Remark: * 1 Selected from the cutting condition as cut depth (d) = 2.9 ± 0.8 mm; feed (f) = 6.8 ± 1.0 m./min; and cutting speed (v) = 1712 m/mim

* 2 To be selected from the cutting condition as cut depth (d) = 3 mm; feed (f) = 3 m/min; and cutting speed (v) = 1712 m/min.

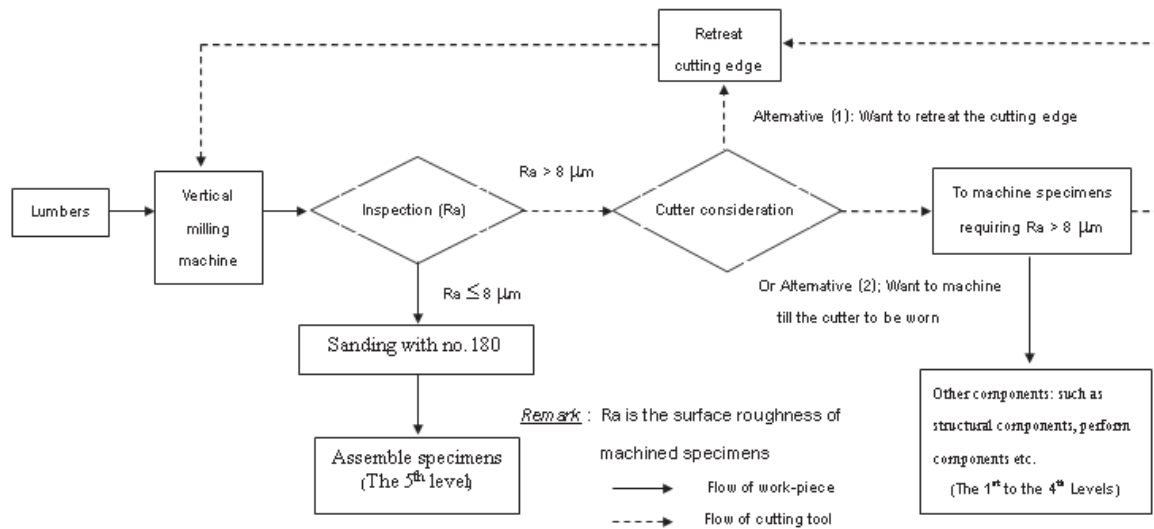


Figure 15. Flow diagram of cutter usage management for the 1st Method created: Want to utilize the cutter beyond the roughness of 8 μm.

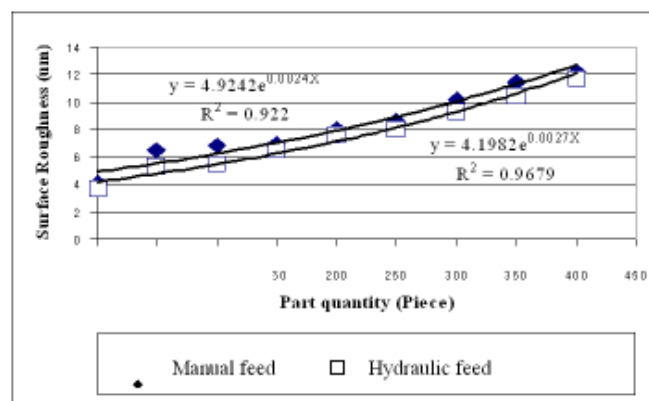


Figure 16. Surface roughness and part quantity cut by manual feed and hydraulic feed.

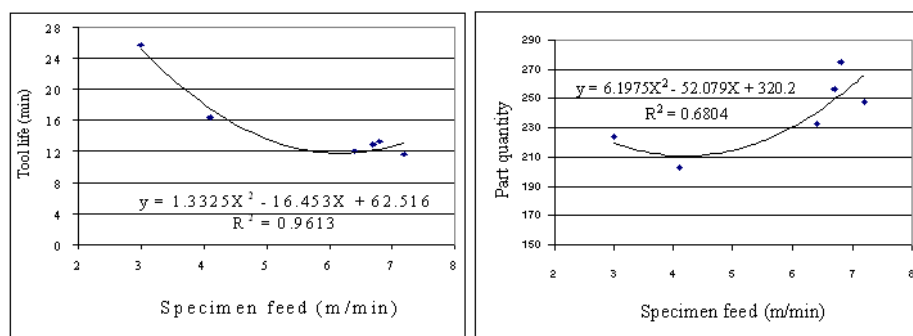


Figure 17. The tool life and cut part quantity were plotted with feed when limited the surface roughness $\leq 8 \mu\text{m}$.

Table 6. Summary of comparative cutting methods applying in production line (To be limited the cut surface roughness $\leq 8 \mu\text{m}$)*

Feed control	Cutting condition			Ra of the 1 st cut (μm)	Cutting time (sec/part) (1)	Cut part Quantity (Part)* (2)	Tool life (Min)* $\frac{(1) \times (2)}{60}$
	Feed (m/min)	Depth (mm)	N (rpm)				
Manual	4.1 \pm 0.9	3	7,900	5	4.86	203	16.44
Hydraulic	3	3	7,900	4	7	239	27.88

Table 7. Comparative results of total sanding times for current and created conditions.

Methods	Sanding with sand paper no. 100			Sanding with sand paper no. 180			Total time (a) + (b) (Min.)
	Time/part (Sec / part)	Part quantity	Time (a) (Minute)	Average Time (Sec / part)	Part quantity	Time (b) (Minute)	
(1) Existing	10.1	400	67.3	6.1	400	40.7	108
(2) Created 1	0	0	0	6.1	200	(20.35) $\times 2^{*1}$	40.7
% difference = $\frac{(1) - (2) \times 100}{(1)}$	100 %					0	62.2 %

Remark: *1 Basis of 400 parts required.

tool life and specimen feed as shown in the Figure 17 by the polynomial power 2 with the R^2 of 0.9613. The best cutting condition found for the study was the feed (f) of 3 m/min, cut-depth (d) of 3 mm, and cutting speed (v) of 1712 m/min, which provided the average tool life of about 25.6 \pm 2.2 minutes determined using the results from the Table 5 and 6 when the cut-surface roughness of 8 μm was considered.

Table 7 provides the comparative results of the total sanding times of the specimen machined by current condition and created method. The total sanding time result for the created method led to a remarkable decrease of the current condition from 108 minute (or 16.2 min/piece) to 40.7 minute (or 6.1 min/piece) or 62.2% reduction.

Conclusions

The conclusions of the study are as follows:

1. The factory lacks of the criteria for cutter usage management. The cutting tool was operated until the cut-part surface became torn grain which needed long-time grinding. The variances of the

cutting condition, in particular manual specimen feed and cut-depth, were high and never controlled. The depth of cut and specimen feed applied by operator were inconsistent, and also were in the ranges of 2.7 to 4.1 mm. and 4.1 to 7.2 m/min, respectively. All of the machined specimens were sanded with the size grits paper number of 100 and then number 180 which totally spent 16.2 min/piece of sanding time.

2. The higher feed of specimen could be the essential cause of decreased tool life and increased surface roughness of the specimen. The suitable cutting condition of the six-tooth vertical milling machine for furniture rubberwood performed in this study was the specimen feed of 3 m/min, the cut-depth of 3 mm, and the cutting speed of 1712 m/min. The tool life of the cutting condition presented was about 25.6 \pm 2.2 minutes when the cut-surface roughness of 8 μm was considered.

3. After applying the guideline with the criteria of changing the cutting tool when the surface roughness of machined specimen was less than 8 μm , the sanding only with the grit paper

number 180 was done and the sanding time decreased from 16.2 sec/piece to 6.1 sec/piece or 62.2 % reduction.

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