Study on the Influence of Cutting Conditions on Machining Surface Quality When Cutting with the FA4060 Milling Machine

Dang Van Truong, Nguyen Van Thinh, Nguyen Xuan Luan, Nguyen Duc Loi

Abstract*— This paper investigates the influence of technological parameters such as spindle speed n and feed rate F on the surface quality of cuts during milling. Experiments were conducted using a CNC milling machine FA4060 with 6 mm thick mahogany wood. Surface quality was evaluated through the surface roughness of the cut. The Taguchi experimental design method was used to assess the influence of each individual parameter on surface roughness. The minimum surface roughness achieved was 1.059 µm corresponding to a spindle speed of 12000 RPM and a feed rate of 200 mm/min. Analysis using the Taguchi method showed that surface roughness was mainly affected by the feed rate, while spindle speed had less influence.

Index Terms*— CNC milling machine, wood, surface roughness, Taguchi method.

I. Introduction

In the field of modern woodworking and mechanical engineering, CNC milling technology plays a key role thanks to its ability to shape parts with complex profiles with high accuracy and productivity. The development of CNC systems not only helps minimize human errors but also significantly improves product quality, especially surface quality – an important technical indicator affecting aesthetics and post-processing finishing [4].

For wood materials, the surface quality of the machined material is affected by the complex interaction of many factors. Experimental studies have shown that parameters such as cutting speed, feed speed and cutting depth have a significant quantitative impact on surface roughness [4]. Usually, increasing the cutting speed within a reasonable range helps improve smoothness, while excessive feed rate often increases the roughness height, leading to a decrease in surface quality [1], [5].

Currently, CNC machine operation is becoming increasingly flexible thanks to the support of specialized CAD/CAM software such as Vectrics Aspire in conjunction with the MACH3 controller [2]. This combination allows for the optimization of programming and G-code output, making it easier for manufacturing facilities to access modern machining technology. However, the operation process also requires strict control of technical factors, especially the heat generated in the control circuit to ensure the stability of the system [3].

Although there have been many studies on the influence of cutting mode on surface quality on different materials, each machine system and specific material (such as mahogany wood) still needs separate studies to find the optimal parameter range [6]. Therefore, experimental research to evaluate the influence of spindle speed and feed rate on surface roughness on the FA4060 milling machine is extremely necessary. The research results will contribute to establishing a rational processing regime, improving product quality and the efficiency of equipment use in actual production.

II. Description of Experiment and Methods

2.1. Materials

The material chosen for this study is acacia wood (scientific name: Khaya senegalensis), a common wood in the Vietnamese furniture and fine art woodworking industry due to its good mechanical properties, fine grain, and beautiful patterns.

To ensure uniformity and accuracy in the CNC milling experiment, the wood samples were prepared with the following specific technical characteristics:

- Sample size: The test samples were machined into square blocks with sides of 5 mm.
- Thickness: The thickness of the material sheet was 6 mm.
- Material condition: The wood had undergone industrial drying to achieve a standard moisture content (approximately 12% - 14%), which helps to minimize warping or cracking during cutting. The workpiece surface was cleaned before the experiment, free from natural defects such as large knots or deep cracks to avoid interfering with the surface roughness measurement results.

Using uniformly sized mahogany wood samples allows for a more objective and accurate assessment of the influence of cutting parameters (spindle speed and feed rate) on the machined surface quality.

2.2. Experimental equipments

The research was conducted on the FA4060 milling machine (Figure 1). This is the main equipment used to perform the cutting process of mahogany wood samples. The FA4060 milling machine is a high-precision mini CNC

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Dang Van Truong, Faculty of Engineering and Technology, Hung Vuong University, Phu Tho, Vietnam
Nguyen Van Thinh, Faculty of Engineering and Technology, Hung Vuong University, Phu Tho, Vietnam
Nguyen Xuan Luan, Faculty of Engineering and Technology, Hung Vuong University, Phu Tho, Vietnam
Nguyen Duc Loi, Faculty of Engineering and Technology, Hung Vuong University, Phu Tho, Vietnam

machine suitable for machining small and medium-sized parts or non-metallic materials such as wood, plastic, and mica. The main technical specifications of the machine include:

- Control system: Uses a Mach3 controller, allowing for the reception and execution of G-code from CAD/CAM software.
- Spindle speed: Flexible adjustment within a wide speed range, meeting the requirements for changing spindle rotation speed with a maximum rotation speed of 24000rpm.
- Machining travel: The machine has a machining area of 40cm x 60cm, ensuring a stable working space and maintaining rigidity throughout the cutting process.

Figure 1. FA4060 milling machine.

To evaluate the surface quality after machining, the study used a Mitutoyo SJ-210 handheld roughness gauge (Japan). This is a contact-type measuring device (using a diamond needle tip) with high reliability and accuracy (Figure 2). The combination of a stable FA4060 milling machine and the accurate Mitutoyo SJ-210 measuring device ensures that the collected data has high scientific value for analysis and optimization. The experiment was conducted at the Mechanical Engineering Practice Room, Hung Vuong University.

Figure 2. Mitutoyo sj-210 roughness meter.

2.3. Experimental design

The Taguchi experimental design method is an orthogonal table-based design method developed by Genichi Taguchi [7]. It is a simple and powerful method for optimizing process parameters. The Taguchi method not only considers the mean value of the experimental results but also focuses on the variability of the data. The signal/noise ratio (S/N) helps to determine the optimal mode by minimizing the impact of noise on the system. There are three common types of S/N ratios:

- Larger is better:

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

- Smaller is better:

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

- Norminal is best:

$$\frac{S}{N} = -10\log_{10}\left(\frac{1}{N}\sum_{i=1}^{n}(y_i - y_0)^2\right) \quad (3)$$

Where, n is the number of value levels of the process parameter, y_i is the measured value at the i^{th} level, and y_0 is the desired value.

In this study, two process parameters were investigated: feed rate (F) and spindle speed (n), with 5 levels used. Therefore, according to the Taguchi method, we have the orthogonal table L25 as shown in Table 1.

Table 1. L25 Orthogonal Array Matrix Based on the Taguchi Method.

No.	**Process parameters**		*No.*	**Process parameters**	
	F (mm/min.)	**n (rpm)**		**F (mm/min.)**	**n (rpm)**
1	160	8000	14	240	12000
2	200	8000	15	300	12000
3	240	8000	16	360	12000
4	300	8000	17	160	15000
5	360	8000	18	200	15000
6	160	10000	19	240	15000
7	200	10000	20	300	15000
8	240	10000	21	360	15000
9	300	10000	22	160	18000
10	360	10000	23	200	18000
11	160	12000	24	240	18000
12	200	12000	25	300	18000
13	160	8000			

III. RESULTS AND DISCUSSION

Machining quality is assessed by the surface roughness Ra of the cut. The surface roughness measurement results are shown in Table 2.

Based on the surface roughness (Ra) measurements in Table 2, we have the following observations:

- Optimal value: The minimum surface roughness achieved is 1.059 µm. This value was obtained under experimental condition 12 with a spindle speed (n) of 12000 RPM and a feed rate (F) of 200 mm/min (Table 2).
- Influence of feed rate (F): The results show that as the feed rate increases (for example, from 200 mm/min to 360 mm/min at the same spindle speed), the roughness Ra tends to increase (Figure 3). This is consistent with cutting theory where a large feed rate increases the roughness of the cut.
- Influence of spindle speed (n): Spindle speed has an influence, but it is not as pronounced as the feed rate. When

increasing the spindle speed from 8000 RPM to 12000 RPM, the surface quality improves (reduces Ra), however, if it continues to increase too much or is not well coordinated with the feed rate, the roughness can vary unstably due to system vibration (Figure 3).

Table 2. Roughness Ra of the cutting surface.

No.	Process parameters		R_a (µm)
	F (mm/min.)	n (rpm)	
1	160	8000	4.080
2	200	8000	1.366
3	240	8000	1.498
4	300	8000	1.997
5	360	8000	1.599
6	160	10000	3.825
7	200	10000	1.270
8	240	10000	1.134
9	300	10000	1.325
10	360	10000	1.679
11	160	12000	3.932
12	200	12000	1.059
13	240	12000	1.361
14	300	12000	1.379
15	360	12000	1.486
16	160	15000	3.670
17	200	15000	1.315
18	240	15000	1.463
19	300	15000	2.040
20	360	15000	1.577
21	160	18000	3.334
22	200	18000	1.257
23	240	18000	1.364
24	300	18000	2.280
25	360	18000	1.387

Table 3. S/N ratio corresponding to 5 levels of input parameters.

Level	F (mm/min.)	n (rpm)
1	-11.502	-5.703
2	-1.930	-4.353
3	-2.656	-4.260
4	-4.919	-5.425
5	-3.763	-5.029
Delta	9.573	1.444
Rank	1	2

The average roughness value corresponding to each level of input parameters is shown in Table 5 and Figure 3.

Table 4. Average value of roughness corresponding to each level of input parameters.

Level	F (mm/min.)	n (rpm)
1	3.768	2.108
2	1.253	1.847
3	1.364	1.843
4	1.804	2.013
5	1.546	1.924
Delta	2.515	0.265
Rank	1	2

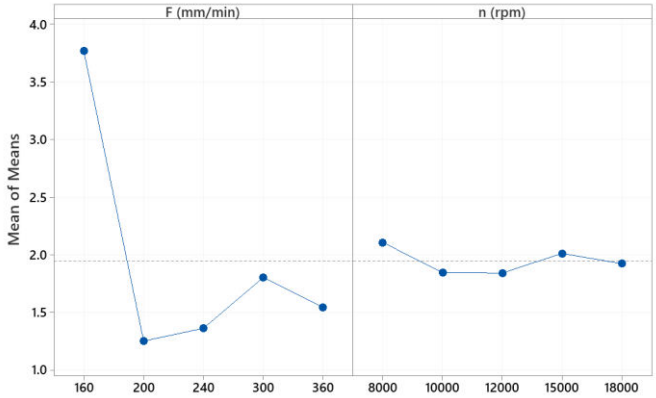

Figure 3. Average roughness corresponding to each level of input parameters.

The research results are completely consistent with the publication of Hoang Viet [1] and Abdullah Sütçü [5] on the fact that feed rate is the leading determining factor for wood surface smoothness when CNC machining. Similar to the research of Ahmed Basil Abdulwahhab [4], increasing the cutting speed (through spindle speed) helps reduce cutting force and significantly improve surface roughness within a certain range.

IV. Conclusion

In This study experimentally evaluated the influence of cutting parameters on surface quality when milling mahogany wood on a FA4060 CNC milling machine. The conclusions drawn from the study include:

- Optimal parameters: Within the scope of the study, the optimal cutting parameters to achieve the smallest surface roughness (Ra = 1.059 µm) are spindle speed n = 12000 rpm and feed rate F = 200 mm/min. This result confirms the ability of the FA4060 milling machine to produce high-quality machined surfaces on natural wood materials.

- Influence of parameters: Through the Taguchi analysis method, the study determined that feed rate (F) is the most decisive and direct influencing factor on surface roughness. Meanwhile, spindle speed (n) has less influence but plays a crucial role in stabilizing the cutting process and minimizing surface scratches on the wood.

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