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Analysis effects of machining parameters on the surface roughness in the milling of thin-walled part made by aluminum Al6061

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***Abstract:** Thin-walled parts are commonly used in many industries including the automotive, aeronautical and precision machines. With low stiffness, thin-walled parts are often deformed in the machining process, so it is difficult to control the machining accuracy, often leading to an increase in the cost of the manufacturing process. In this study, a Taguchi experimental model is used to predict and evaluate the influence of cutting parameters on the surface roughness of thin walled parts in the AL6061 aluminum milling process. Research results show that the feed per tooth has the greatest influence on surface roughness. The minimum value of surface roughness is achieved when milling with a set of cutting parameters (cutting speed V=300m/min, fz=0.04 mm/tooth, cutting depth 0.3mm and cutting width 12mm).*

***Keywords:**Thin wall, Aluminum, Surface roughness, Al6061, Milling*

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I. INTRODUCTION

Nowadays, thin-walled parts made of aluminum are widely used in industrial production. The thin walled parts usually have the thickness about 1mm to 5 mm. Especially, aluminum alloy thin-walled parts are popularly used in the aviation industry because it has many advantages, such as: The weight of thin-walled parts is significantly reduced compared to solid parts while still ensuring accuracy requirements as well as ensuring bearing capacity [1]; Using thin-walled parts can remove up to 95% of the weight of the original assembly [2]; Using thin-walled parts can reduce production costs by reducing assembly volume, materials, management costs, and storage costs...[1,3]; Using thin-walled parts can increase the composite accuracy of the product [1].

However, because thin-walled sections have low stiffness, vibrations often occur during machining, which reduce surface quality and product accuracy.

To ensure the machining accuracy, the deformation should be controlled during the working process. The deformations of the part can be divided into two types: deformation due to machining and deformation after machining. Machining strain is generated during cutting the part of the material containing the initial residual stress, while the post-machining strain (subsequent strain) (usually occurs due to the existence of residual machining stress) occurs after assembly is complete. Many cases have been reported from industry for similar examples where thin-walled parts were discarded because of subsequent deformation. In machining, milling is a common process used to machine thin-walled parts. The milling process of thin-walled details has been focused on by many researchers.

Machining residual stress studies often focus on analyzing and predicting residual stress patterns by considering various processing parameters, tooling parameters, and others. Khabeery and Fattouch (1988) found that the amplitude of residual stress generally increases with increasing feedrate, depth of cut and tensile strength of the part material [1]. Kuang and Wu (1995) found that cutting speed, feed amount, and tip radius have a significant effect on residual stress [2]. Coto et al. (2011) showed that increasing toolpath will increase tensile residual stress, however by increasing shear speed will reduce tensile residual stress [3]. Navas et al. (2012) note that by reducing the amount of feed and increasing the cutting speed, it is possible to reduce the tensile residual stress when machining AISI4340 steel [4].

Thus, it is very difficult to control the form and magnitude of residual stress of the machined surface. And there are no clear rules given when using different processing materials and with different technological parameters. For example, Mohammadpour et al. (2010) showed that the maximum value of surface layer residual stress (MMSRS) is 680MPa, and the depth of shear corresponding to the maximum compressive residual stress is 200 millimeters [5]. Liang and Su (2007) measured the MMSRS as 900 MPa, the DMCRS ranging from 25 to 100 micrometers [6]. However, Ulutan et al. (2007) found the MMSRS to be 1200 MPa and the DMCRS to be even smaller than 10 micrometers [7]. The influence of factors on different structures during heat reduction is studied and calculated. Robinson et al. (2011) discussed the mechanism of redistribution of residual stress after machining for Al7449 material after heating [8]. By removing the material in layers, the effect of residual stress redistribution on strain is discussed. While there is no indication of stress reduction, and the model is limited to the cubic rule. In summary, all studies are based on the thickness of each layer (equal or nearly equal) of the work piece, so it is difficult to apply to the machining of thin-walled parts, where the depth variable machining. Therefore, it is necessary to further analyze the redistribution of residual stress of thin-walled parts with different cutting depths during machining, thereby reducing the deformation of thin-walled parts.

Many researchers have focused on studying the process of machining thin-walled parts, the deformation that occurs during part milling. A few studies focus on determining the influence of technological parameters on deformation and surface roughness. Ning et al. [9] used the finite element method (FEM) to calculate the thin-walled structural deformations during machining. Budak [10] developed an analytical model to avoid vibration during high-performance milling without sacrificing productivity. Tang and Liu [11] simulated and calculated the deformation of the part using FEM. Shamsuddin et al. studied the best tooling strategy for machining aluminum alloy thin-walled parts [12]. Seguy et al. built a numerical model using stable zone theory to study surface roughness and vibration when machining thin-walled parts [13]. The dynamic interaction between the cutting tool and the spindle was analyzed using FEM by Mane et al. [14]. Davies et al. studied the oscillations of thin walls during milling [15]. Benardos et al. used different methods to predict the change of surface roughness [16]. Thevenot et al. aims to optimize cutting conditions and accurately identify milling cases where fluctuations are not apparent during machining of thin-walled parts [17].

Several articles also describe studies on the influence of toolpath planning strategies and tool-related parameters such as coating, tool diameter, helix angle on surface roughness and roughness. exact thickness of parts. Wan et al. developed a new theoretical method to study the working mechanism of the helix angle and obtain the optimal helix angle for milling cutters when milling the outer profile [18]. The author has proved that the maximum value of the shear force decreases when increasing the torsion angle in the case of single-edge cutting. Jabbaripour et al. improved the geometrical accuracy and surface integrity of thin-walled parts during the finishing process [19]. They analyzed the influence of cutting direction and cutting speed on the amplitude of the cutting force and the quality of the machined surface. Durakbasa et al. focused on studying the effect of tool coating and tool radius on surface quality in AISI H13 steel finishing process [20]. Herranz et al. proposes feed strategies by analyzing the static and dynamic phenomena occurring during high-speed milling. The authors have given some useful advice when machining low hardness parts [21]. Polishetty et al. studied tool wear, surface roughness and cutting force in machining titanium alloy Ti-6Al-4V using trochoidal toolpaths [22]. Izamshah et al. studied the influence of three toolpath strategies including “water line-step”, “overlapping-step” and “tree wise-steps” on machining accuracy [23]. The results show that the feed strategy affects the accuracy of thin-walled parts and the results show that the waterline-step tooling strategy has the most influence on the machining accuracy. Vakondios et al. also studied the effect of toolpaths on surface roughness during the aluminum alloy finishing process [24]. Subramanian et al. conducted an experimental study on the influence of milling cutter geometry parameters on vibration during milling [25]. Kadirgama et al. studied to optimize surface roughness when milling aluminum alloy (AA6061-T6) with carbide coated cutting tools [26]. Karkalos et al. used RSM to develop a quadratic relationship between input and output parameters in the peripheral milling of titanium alloys [27]. Furthermore, a simulation model based on artificial neural network (ANN) is also developed. Thus, according to the published documents on the milling process of thin-walled parts, the study to determine the reasonable technological regime when processing thin-walled aluminum alloy parts has not been interested by many authors. In this study, we adopted the surface roughness of the thin-walled parts in the aluminum machining process. The effects of the cutting parameters and interactions between them to the surface roughness in this process were analyzed by the Taguchi model.

II. EXPERIMENT AND METHOD

In the study, all trials were carried out on the Mazalk 530C CNC milling center at the CAD/CAM-CNC laboratory of the Thai Nguyên University of Technology in Viet Nam. The machining process uses a cutting tool specialized in processing aluminum alloy materials of Korean company YG with code 36588. The cutting tool is made of uncoated carbide material with 3 cutting teeth, twist angle 45 and a cutting length of 60 mm. The workpieces are made by aluminum alloy Al6061 with a thickness of 3mm. The surface roughness is measured by Mitutoyo's SJ210 roughness gauge.

Figure 1. The experimental devices

YG end mills are used for machining with high cutting speed and high machining productivity. However, the manufacturing company only gives the recommended cutting mode for all cases with the same diameter. Based on the technological capabilities of the experimental system and recommendations from the manufacturer, a set of technological parameters with value levels is selected as shown in Table 1.

Table 1. Cutting parameters and level

	Cutting parameters	**symbols**	**Level**		
			1	**2**	**3**
1	Cutting speed – A (m/min)	A	250	300	350
2	Feed per tooth - B (mm/tooth)	B	0.02	0.04	0.06
3	Radial depth of cut – C (mm)	C	0.3	0.6	1.2
4	Axial depth of cut – D (mm)	D	8	12	16

In this research, a experimental model with 9 trials is built by using Minitab 18 Software (Minitab Inc., USA) with Taguchi method. The experimental matrix is shown table 2. The surface roughness of thin wall parts was measured after milling and shown in table 3.

Table 2. Experimental model L9

No.	**A**	**B**	**C**	**D**
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 3. The experimental results and the S/N ratios for the surface roughness

Exp. No	V (m/min)	fz (mm/tooth)	a (mm)	b (mm)	Ra (µm)	S/N Ra
1	250	0.02	0.3	8	0.217	13.2575
2	250	0.04	0.6	12	0.112	19.0415
3	250	0.06	1.2	16	0.267	11.4806
4	300	0.02	0.6	16	0.203	13.8644
5	300	0.04	1.2	8	0.176	15.0733
6	300	0.06	0.3	12	0.144	16.8328
7	350	0.02	1.2	12	0.250	12.0296
8	350	0.04	0.3	16	0.133	17.5012
9	350	0.06	0.6	8	0.229	12.8033

III. RESULT AND DISCUSSION

Effect of cutting parameters to the surface roughness of the thin wall part

The influence of technological parameters on surface roughness during the milling of aluminum alloy thin-walled parts was analyzed using Minitab. The analysis results show that the average value of the roughness corresponds to different levels for each survey parameter and the order of influence of the parameters on the roughness value is shown in table 4. The analysis results show that among the investigated parameters, the feed per tooth is the parameter that has the strongest influence on the average value of the machined surface roughness.

Table 4. Response Table for Means

Level	Cutting speed	Feed per tooth	Radial depth of cut	Axial depth of cut
1	0.1986	0.2234	0.1649	0.2076
2	0.1743	0.1404	0.1811	0.1687
3	0.2042	0.2132	0.2311	0.2009
Delta	0.0299	0.0830	0.0662	0.0389
Rank	4	1	2	3

The influence of the cutting parameters and their interactions on the surface roughness value of the machined surface is shown in Figures 2. The results show that: When increasing the cutting speed from 250 m/min to 300 m/min, the surface roughness value decreases, but the roughness increases with increasing to 350 m/min. In the survey range, the surface roughness reached the smallest value with cutting speed 300m/min. The feed per tooth also strongly affects the surface roughness, the roughness reaches the smallest value with fz 0.04mm. Meanwhile radial depth of cut increases, the surface roughness also increases. The axial depth of cut has little effect on the surface roughness. The interaction effect between the survey parameters on the average surface roughness is also analyzed and shown in Figure 3. The results also show that the interaction between the technological parameters has a significant influence on the surface roughness. Especially at cutting speed 3000m/min, feed per tooth fz 0.04mm/tooth, radial depth of cut 0.3 mm and axial depth of cut 12mm, the surface roughness reach to the minimum value.

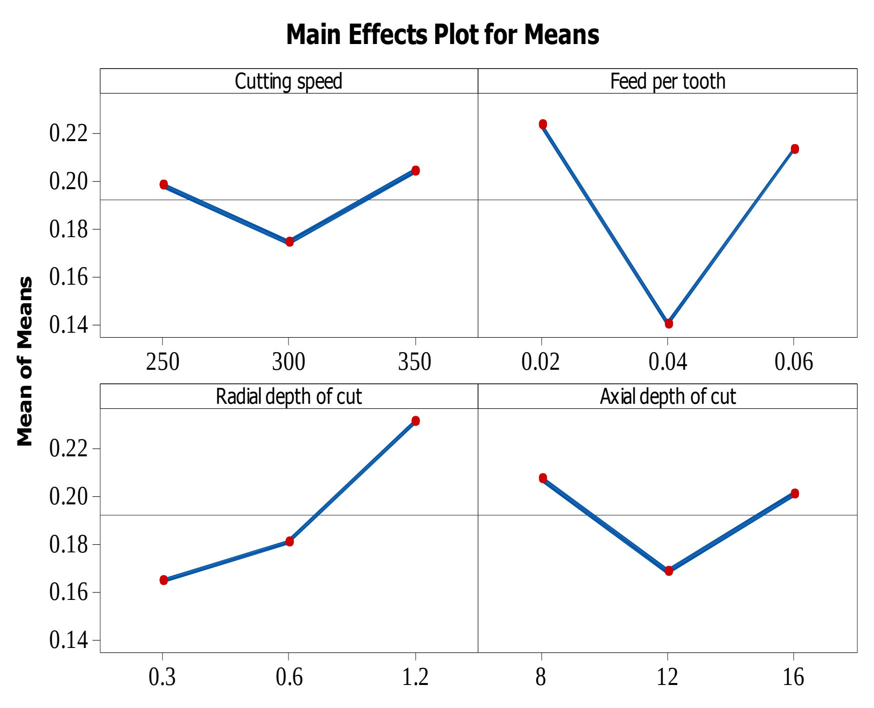

Figure 2. Effects of input parameters on the surface roughness

Using Minitab software, analyze the influence of cutting parameters on the signal-to-noise ratio S/N calculated for the surface roughness. The analysis results show that the signal-to-noise ratio for the surface roughness corresponds to different levels for each survey parameter and the order of influence of the parameters on the S/N ratio value of the surface roughness. The analysis results in table 5 show that among the investigated parameters, the feed per tooth and the radial depth of cut are the parameters that have the strongest influence on the S/N ratio of the surface roughness of the machined surface.

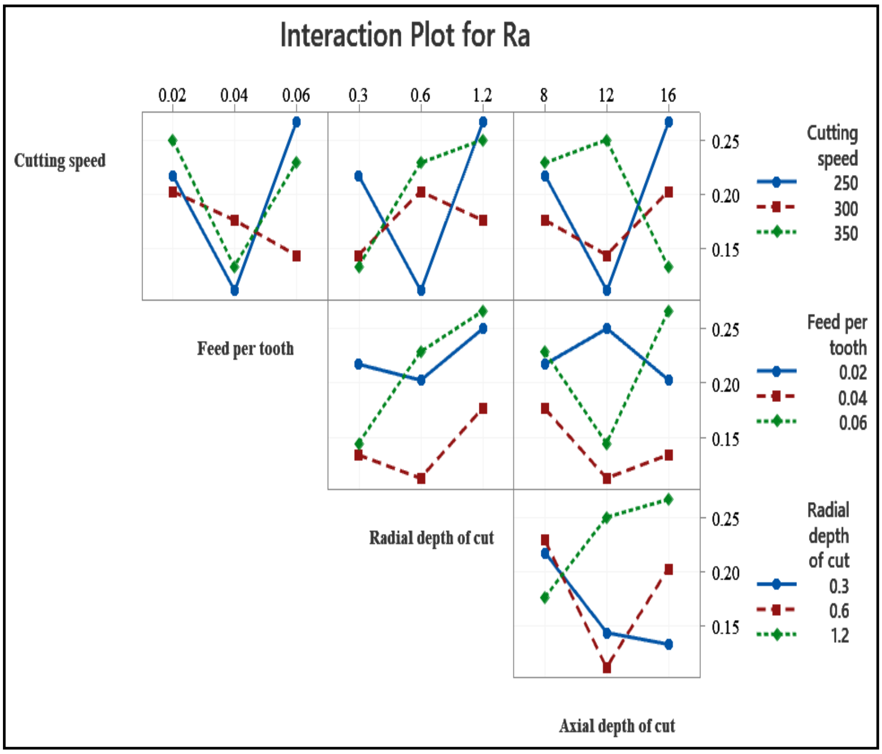

Figure 3. Interaction effect of cutting parameters on the surface roughness

Table 5. Response Table for Signal to Noise Ratios

Smaller is better				
Level	Cutting speed	Feed per tooth	Radial depth of cut	Axial depth of cut
1	14.59	13.05	15.86	13.71
2	15.26	17.21	15.24	15.97
3	14.28	13.71	12.86	14.28
Delta	1.15	4.15	3.00	2.26
Rank	4	1	2	3

The influence of the cutting parameters on the S/N ratio of the surface roughness on in the milling thin wall part is shown in Figure 4. The results show that the ratio S/N increases rapidly with increasing cutting speed and has the greatest value with cutting speed 350m/min. At the same time, the value of the s/N ratio decreases sharply when the cutting width is increased. While the feeed rate and radial depth of cut do not have a strong influence on the S/N ratio of the surface roughness. The S/N ratio of the part deformation reached the maximum value with the parameter set V=300m/min, fz=0.04mm/tooth, a=0.3mm and b=12mm. The interaction influence between the cutting parameters on the S/N ratio of the surface roughness is also analyzed and shown in the figure 5.

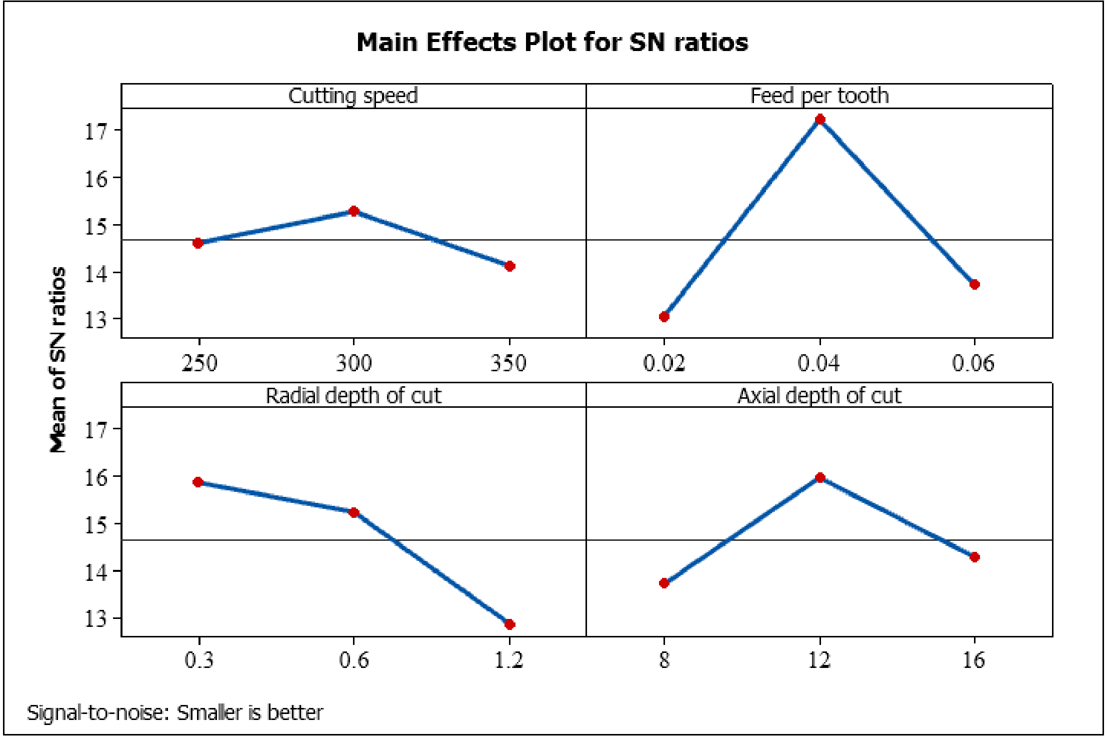

Figure 4. Influence of cutting parameters on the S/N ratio for the surface roughness of thin wall part in the milling process

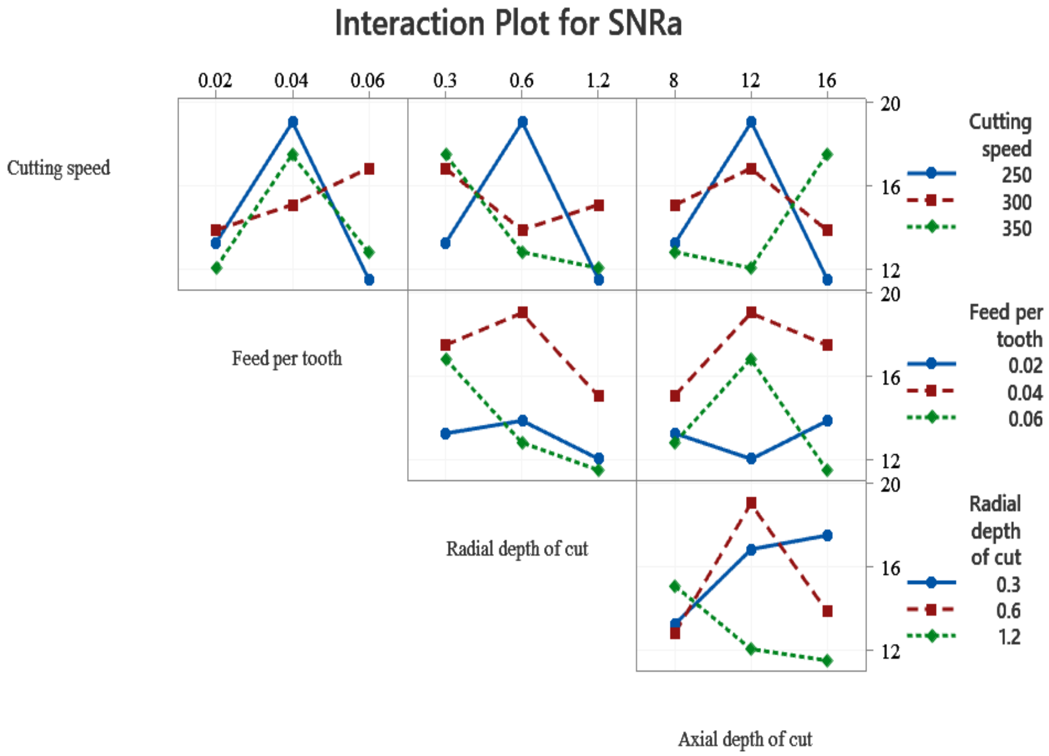

Figure 5. Interaction effect of cutting parameters on the surface roughnessof the thin wall part

IV. CONCLUSION

An experimental Taguchi model was used to study the influence of cutting speed, feed rate, radial depth of cut and axial depth of cut on the surface roughness of thin wall part in the milling process. The researched results indicated that the feed rate and depth of cut are the strongest influence parameters on the surface roughness. In this research, the surface roughness reaches the minimum value with the technological parameter set: cutting speed V=300m/min, fz=0.04 mm/tooth, cutting depth 0.3mm and cutting width 12mm.

V. ACKNOWLEDGMENT

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