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Effect of Cutting Parameters for Cutting Forces, Tool Wear, Microstructure Changes and Surface Roughness in Milling SUS 304

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Abstract
Austenitic stainless steel are hard materials to machine, due to their high strength, high ductility and low thermal conductivety. This paper aims to determine the effects of cutting parameters for cutting forces, tool wear, microstructure changes and surface roughness when milling SUS 304 using Sandvik M1025R08 insert. The forces, tool wear, microstructure changes and surface roughness were measured by force dynamometer Kisler 9257BA, SEM and Mitutoyo SJ-201, respectively. The design of experiments (DOE) is the full factorial method. The results show the effects of each parameter on the cutting force, tool wear, microstructure changes and surface roughness; the optimum condition is cutting speed 175m/min and feed rate 0.2 mm/teeth.
Keywords: *Milling SUS304,SUS 304, the full factorial method, microstructure changes, stainless steel*

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I. INTRODUCTION

Stainless steel is a steel-based alloy with high Chromium (Cr) and Nickel (Ni) content, so it is slow to oxidize and can withstand strong acidic environments. Therefore, stainless steel (especially SUS 304) is widely used in the chemical industry, household appliances, shipbuilding industry and recently used as molds in the medical industry [7].

When machining stainless steel, there are some difficulties: the flexible, heat-resistant material causes stickiness, the chip formation process is very difficult, causing high cutting heat, high cutting force... which negatively affects the machining accuracy and the durability of cutting tools.

R.A. Mahdavinejad and Saeedy studied the influence of technological regime on tool wear and surface roughness when turning SUS 304 steel, TiC-coated cutting tools. The results showed that tool wear was greatly affected by cutting speed, and tool wear decreased when cutting speed increased. Surface roughness is greatly affected by the feed rate, so surface roughness can be improved by reducing the feed rate and increasing the cutting speed. The author also confirmed that flooding lubrication is more effective than dry machining.[12]

Ihsan Korkut, Ulvi Seker studied the effect of cutting speed on surface roughness and tool wear when turning stainless steel using ceramic cutting tool material under dry cutting conditions. The author determined that the optimal cutting speed for both parameters is 180 m/min.[6]

K.A Abou – El – Hossein et al. studied the application of inserts with improved geometric parameters to machine SUS 304 stainless steel. The results determined the optimal cutting conditions to significantly improve the tool life. [7]...

This paper aims to determine the influence of cutting mode on cutting force, tool wear, surface microstructure and surface roughness when milling SUS 304 steel using Sandvik M1025R08 inserts suitable for domestic production conditions.

II. EXPERIMENTAL SETUP

The experiment was carried out on a box-shaped work-piece, size 75 x 75 x 100 mm; the material is stainless steel SUS 304 with chemical composition and mechanical properties shown in Table 1 and Table 2

Table 1. Chemical composition of SUS 304 steel

C	Mn	Si	P	S	Cr	Ni	N
0.08	2.0	0.75	0.045	0.03	18-20	10.5	0.1

Table 2. Mechanical properties of SUS 304 steel		
Tensile strength	Compressive strength	Hardness
520 Mpa	210 MPa	92 HRB

The processing equipment includes a CNC milling machine VMC-85S at the Experimental Center of Thai Nguyen University of Technology; M1025R08 Sandvik inserts are shown in Figures 1 and 2.

Figure 1. CNC milling machine VMC-85S


Figure 2. M1025R08 Sandvik inserts

The experiment was carried out with 4 cutting speed levels of 125, 150, 175 and 200 m/min; 3 feed rates of 0.1, 0.2 and 0.3 mm/tooth; the depth of cut was kept fixed at 0.5mm; lubrication was by the flooding method. The experimental levels are shown in Table 3

Table 3. Experimental setup levels				
	Level 1	Level 2	Level 3	Level 4
Cutting speed v (m/min)	125	150	175	200
Feed rate S (mm/tooth)	0.1	0.2	0.3	

Experimental design using the "two orthogonal factors" method. This method allows to study two experimental factors simultaneously and to test all combinations between different levels of experimental factors [9]. Each experimental point is repeated 3 times. Cutting force is measured in all 3 repetitions, then the average value of the 3 measurements of all 3 force components Fx, Fy, Fz is taken. Surface roughness is measured 3 times and then the average value is taken. After a cutting time corresponding to a cutting length of 1200 mm, stop machining, take the insert and take an SEM to determine the tool wear. At the first cut, take the machined surface and take an SEM to determine the surface microstructure.

III. RESULTS AND DISCUSSION

The influence of cutting speed and feed rate on the surface roughness parameter Ra is shown in Figure 3. Feed rate and cutting speed are two main factors affecting the value of surface roughness, in which the influence of feed rate is greater. The interaction effect of the above two factors is insignificant. In the cutting speed range of 125 m/min to 200 m/min, when the cutting speed increases, the surface roughness decreases. With the feed rate values, when the feed rate increases, the surface roughness increases. The surface roughness reaches the smallest value when V = 200 m/min and S = 0.1 mm/tooth is 0.42 μm. This is explained by the fact that when machining ductile materials such as SUS 304, tool gouge often appears. The tool gouge is formed and reaches a larger value at low cutting speed and large feed rate. This chip mass is continuously formed and lost, causing the cutting force to change, causing vibration and adversely affecting the quality of the machined surface. Therefore, when the cutting speed increases, the chip phenomenon decreases, the influence of the chip on the surface roughness decreases, leading to a decrease in the surface roughness when the cutting speed increases. In addition, when the cutting speed increases and the feed rate decreases, the degree of deformation in the chip formation area decreases, the chip roll radius increases, the chip thickness decreases, causing the cutting force and vibration to decrease. Due to the reduction of cutting force and vibration, the influence of plastic deformation and vibration of the technological system on the surface roughness decreases. As a result, when the cutting speed increases and the feed rate decreases, the surface roughness will decrease.

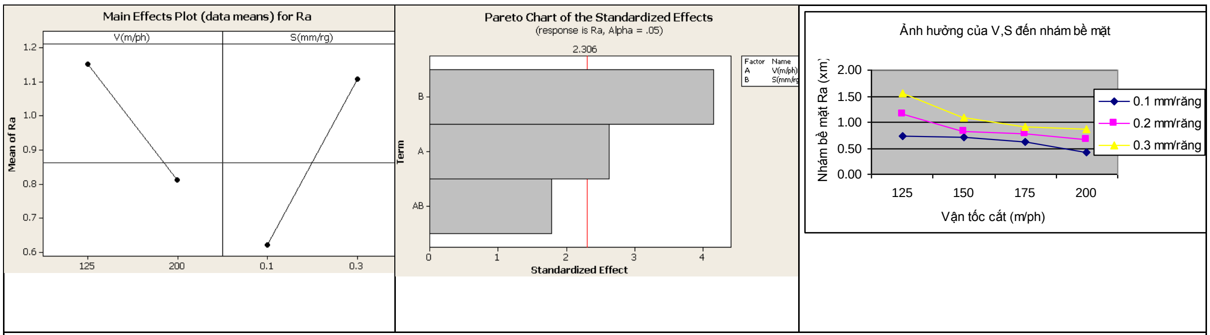


Figure 3. Influence of factors on Ra

Figure 4 shows that the feed rate S and cutting speed v are the main factors affecting the cutting force, the interaction effect of S, v is insignificant. In the cutting speed range from 125 m/min to 200 m/min, when the cutting speed increases, the cutting heat increases, the impact of cutting heat is stronger. Cutting heat reduces the mechanical properties of the workpiece, changes the friction process between the chip and the front surface, causing the friction coefficient to decrease, leading to the tendency of all three force components to decrease when the cutting speed increases.

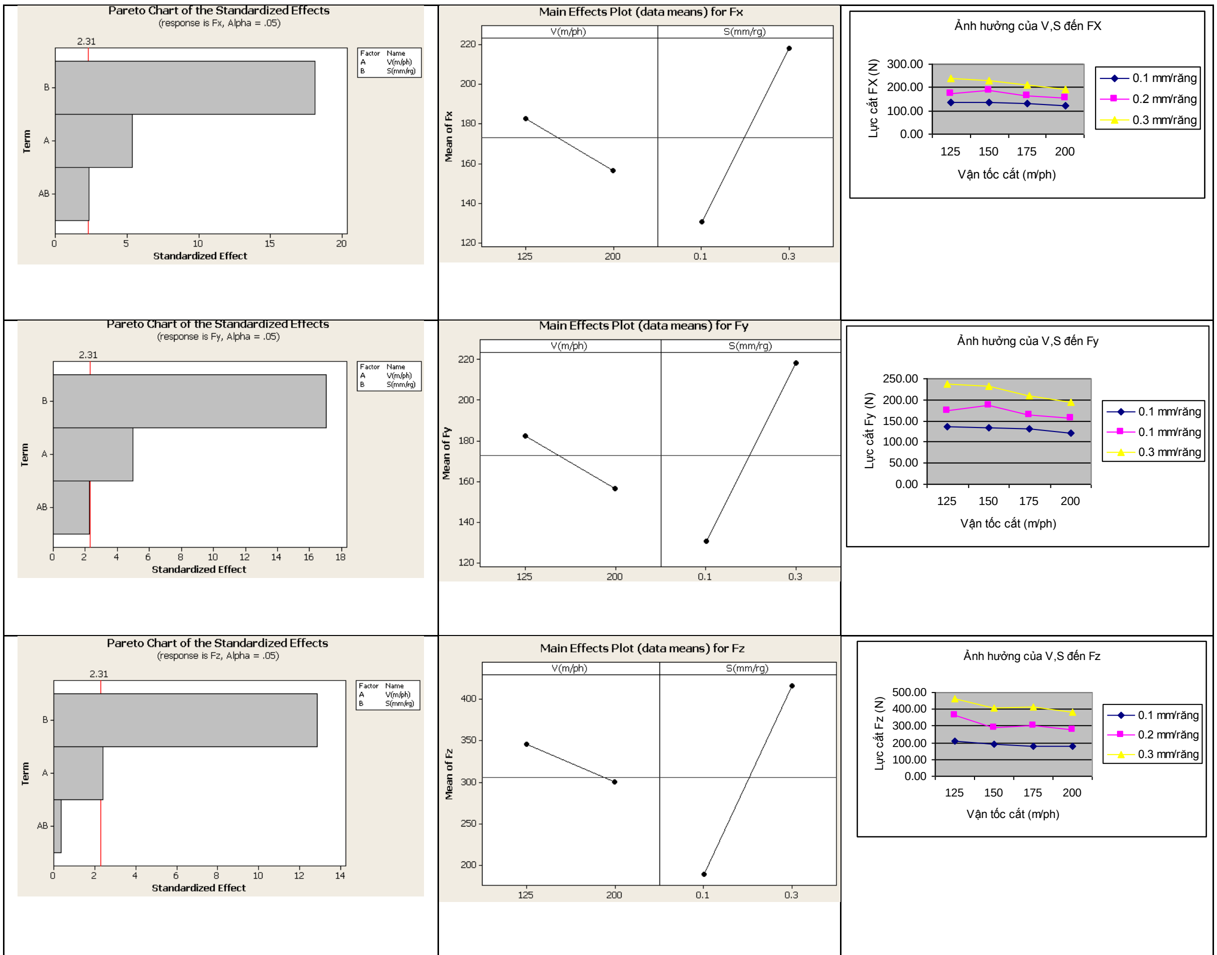


Figure 4. Influence of factors on cutting force

Figures 5 and 6 show that the wear phenomenon mainly occurs on the front face of the cutting tool. This is consistent with previous studies. When machining SUS 304, the tool-chip contact area can be considered as the width of the cutting edge and is the area with higher cutting heat than other areas. The area with the highest temperature is at the end of the cutting edge [8]. The amount of tool wear is mainly affected by the thermal conductivity of the workpiece material. The cutting heat generated is mainly transferred to the chip, the amount of heat transferred to the tool is only about 10% - 40%. When cutting at low cutting speed, the contact time between the front face of the tool and the chip increases, the time for chip movement out of the cutting area slows down, causing more cutting heat to be transferred to the tool, reducing the hot hardness of the tool. As a result, at the lowest cutting speed (125 m/min), the amount of tool front wear reaches a maximum value of 112.3 µm. When the cutting speed increases to 200 m/min, the cutting heat increases, the heat transferred to the tool tends to increase, as a result the amount of cutting tool wear begins to increase.

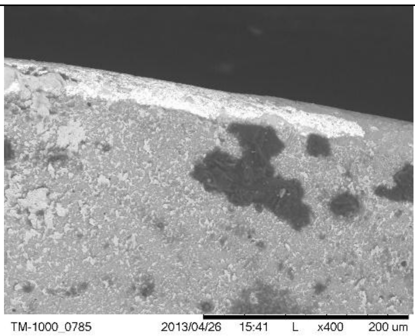


Figure 5. Back face wear

(v=125 m/min; S=0.2 mm/tooth)

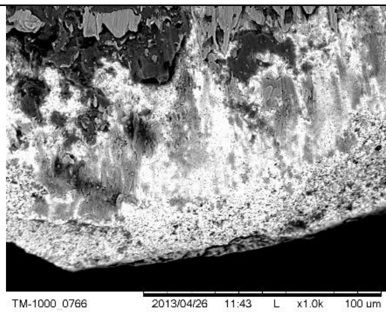


Figure 6. Front face wear

(v=125 m/min; S=0.2 mm/tooth)

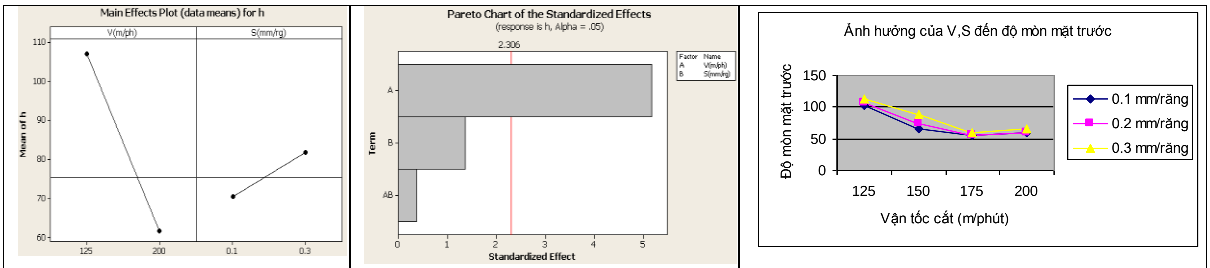
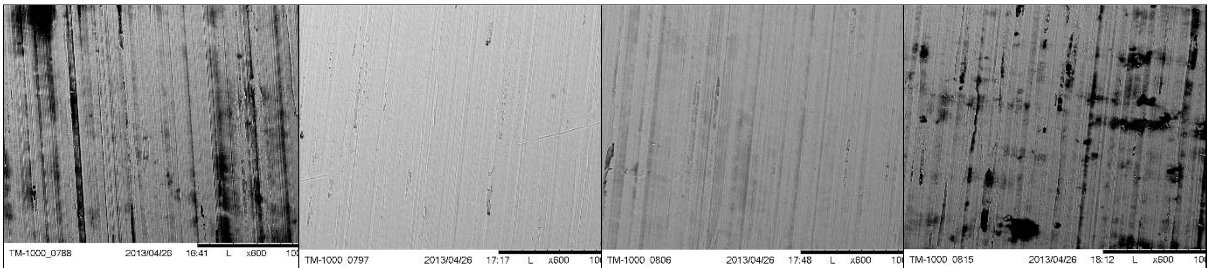


Figure 7. Effect of v, S on tool wear

Figure 8 shows the SEM images of the surface microstructure of the machined part surface corresponding to different cutting points. The surface microstructure is changed under the effects of cutting heat, cutting force and chemical energy.



v = 125 (m/min) S = 0.2 (mm/tooth)	v = 150 (m/min) S = 0.2 (mm/tooth)	v = 175 (m/min) S = 0.2 (mm/tooth)	v = 200 (m/min) S = 0.2 (mm/tooth)

Figure 8. Surface microstructure

The surface SEM results show that at a low cutting speed of 125 m/min, the surface of the machined part appears many micro-cracks and the machining marks are clear. This can be explained by the fact that the effect of cutting force and tool backspin at this cutting point reaches its maximum value, causing the plastic deformation of the machined surface to be the largest. When the cutting speed increases in the range of 125 m/min to 175 m/min, the cutting heat increases, while the tool backspin and cutting force decrease. These two factors offset each other and as a result, the reduction of cutting force and tool backspin has a more obvious effect. As a result, the machined surface becomes cleaner, less pitted, and less deformed. The most "beautiful" surface microstructure is at the cutting point v = 175 m/min, S = 0.2 mm/tooth

When the cutting speed is 200 m/min, the cutting heat generated is large, the effect of cutting heat is dominant. As a result, the surface appears with many cracks, microscopic pits.....

IV. CONCLUSION

1. For surface roughness, the two factors S and v both have an important influence on the formation of the tool's edge. When cutting at high speed, with a small feed rate, the surface roughness achieves good results.

2. For cutting force. Of the three force components, the force component Fz has the largest value. The two factors S and v both have an important influence. When the cutting speed increases, the cutting heat increases, making the material easier to cut. As a result, when the cutting speed increases, the cutting force decreases.

3. For tool wear, when the cutting speed increases, the chip-tool contact time decreases. The amount of heat transferred to the tool decreases, leading to a tendency for tool wear to decrease when the cutting speed increases.

4. For the surface microstructure, it is affected by both cutting force and cutting heat. The most beautiful surface microstructure is at v = 175 m/min and S = 0.2 mm/tooth.

5. Recommended cutting speed is v = 175 m/min and S = 0.2 mm/tooth.

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