Research on the Influence of Cutting Parameters on Surface Quality in CNC Plasma Cutting

Dang Van Truong, Le Quoc Trieu, Nguyen Van Thinh

***Abstract*— This paper investigates the influence of technological parameters such as cutting voltage (corresponding to cutting height) and cutting speed on the surface quality of the cut when machining with a CNC plasma cutting machine. The experiment was conducted using an HNC 1500W CNC plasma cutting machine on SS400 steel with a thickness of 5mm. Surface quality was evaluated based on the surface roughness of the cut. The Taguchi experimental design method was used to assess the impact of each individual parameter on surface roughness. The minimum surface roughness achieved was 1.5 µm, corresponding to a cutting voltage of 120 V and a cutting speed of 1700 mm/min. The analysis results using the Taguchi method indicate that surface roughness is mainly influenced by cutting voltage (which corresponds to the cutting height), while cutting speed has a lesser effect.**

***Index Terms*— Plasma cutting machine, surface roughness, Taguchi method, SS400 steel.**

I. Introduction

The plasma cutting process was developed about thirty years ago [1]. In this process, a high-pressure ionized gas stream, called plasma, is used as a heat source to cut metals such as carbon steel, stainless steel, aluminum, copper and other metals or alloys [2], [3]. For steel materials, the gas stream used is usually compressed air to obtain good quality at faster cutting speeds [9]. The advantage of the plasma cutting method is that it can cut thicker materials than other methods [8]. Furthermore, the plasma cutting method can achieve high quality when cutting grooves with complex profiles as well as can automate the cutting process easily. Therefore, today, CNC plasma cutting technology (computer controlled cutting process) is widely used in mechanical manufacturing to improve productivity as well as enhance cutting quality. In the CNC plasma cutting process, technological factors such as cutting speed, gas pressure, cutting voltage (cutting height) and cutting current have a great influence on product quality [3], [4], [6]-[8]. Salonitisa studied the plasma cutting process on 15mm thick S235 mild steel using a CNC plasma cutting machine. The research results showed that the cutting distance (cutting voltage) has a significant influence on surface roughness [3]. Kechagias's study on 15mm thick steel also showed that the parameters that most affect the quality of the cut are cutting speed and cutting voltage [4].

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Although many studies have been conducted on CNC plasma cutting machines to evaluate the influence of cutting process parameters on cutting quality. But studies aimed to optimize the quality of cut products with small cutting currents (below 65A) and small workpiece thicknesses (below 8mm) have not been clarified. Therefore, in this study, experiments were conducted with a cutting current of 60A and a workpiece thickness of 5mm to evaluate the influence of cutting speed and cutting voltage on the quality of cuts.

II. Description of Experiment and Methods

2.1. Materials

In this study, the material used is SS400 steel, which is a low-carbon steel, widely used in industry because of its good mechanical properties, such as hardness, tensile strength and heat resistance. In this study, samples with dimensions of 50 mm long and 50 mm wide were cut from 5 mm thick SS400 steel plate. The chemical composition of SS400 is illustrated in Table 1.

Table 1. Chemical composition of SS400 steel.

%C	%Mn	%Si	%S	%P
0.14 – 0.22	0.40 – 0.60	0.12 – 0.30	≤ 0.05	≤ 0.04

2.2. Experimental equipments

The experiment was performed on HNC 1500W CNC plasma cutting machine (Figure 1). The machine consists of main parts such as power source, plasma cutting torch, guide bar, control system and cutting table. The technological parameters of the cutting process are set directly on the machine's control panel.

Figure 1. HNC 1500W CNC plasma cutting machine.

In this study, the quality of the cut product (surface roughness Ra of the cut) is evaluated by Mitutoyo sj-210 roughness meter (Figure 2).

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 [8]. 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 studied including cutting voltage (U) and cutting speed (V) with 5 levels of values used, so according to Taguchi method, we have orthogonal table L25 as shown in Table 2.

Table 2. L25 Orthogonal Array Matrix Based on the Taguchi Method.

No.	Process parameters		No.	Process parameters	
	U (Volt)	V (mm/min.)		U (Volt)	V (mm/min.)
1	110	1400	14	130	1700
2	110	1500	15	130	1800
3	110	1600	16	140	1400
4	110	1700	17	140	1500
5	110	1800	18	140	1600
6	120	1400	19	140	1700
7	120	1500	20	140	1800
8	120	1600	21	150	1400
9	120	1700	22	150	1500
10	120	1800	23	150	1600
11	130	1400	24	150	1700
12	130	1500	25	150	1800
13	130	1600			

III. Results and Discussion

The machining quality is evaluated by the surface roughness (Ra) of the cut. The surface roughness measurement results are shown in Table 3. The measurement results show that the minimum surface roughness obtained is 1.5 μm corresponding to a cutting voltage of 120 V and a cutting speed of 1700 mm/min.

Table 3. Roughness Ra of the cutting surface.

No.	Process parameters		R_a (μm)
	U (Volt)	V (mm/min.)	
1	110	1400	3,076
2	110	1500	2,147
3	110	1600	2,067
4	110	1700	3,123
5	110	1800	2,123
6	120	1400	2,089
7	120	1500	2,546
8	120	1600	2,212
9	120	1700	1,500
10	120	1800	1.770
11	130	1400	4,156
12	130	1500	2,784
13	130	1600	2,821
14	130	1700	1,948
15	130	1800	2,404
16	140	1400	1,920
17	140	1500	2,012
18	140	1600	1,658
19	140	1700	2,028
20	140	1800	2,672
21	150	1400	2,328
22	150	1500	1.900
23	150	1600	2,070
24	150	1700	3,912
25	150	1800	5,360

The influence of technological parameters of the cutting process on surface roughness is evaluated by the Taguchi method using the S/N ratio in the case of *Smaller is better* because the lower the surface roughness, the better the surface quality. Based on the measurement results obtained in Table 3, using formula (2), we can calculate the S/N ratio with 5 levels of the selected input parameters (Table 4). The results in Table 4 show that the variation (Delta) of surface roughness when cutting voltage U changes is 3.154 while this variation is 1.863 when cutting speed V changes. This proves that cutting voltage U is the main factor affecting the quality of the cut surface (Rank 1).

Table 4. S/N ratio corresponding to 5 levels of input parameters.

Level	U (V)	V (mm/min.)
1	-7.827	-8.308
2	-5.979	-7.059
3	-8.737	-6.584
4	-6.162	-7.439
5	-9.133	-8.447
Delta	3.154	1.863
Rank	1	2

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

Table 5. Average value of roughness corresponding to each level of input parameters.

Level	U (V)	V (mm/min.)
1	2.507	2.714
2	2.023	2.278
3	2.823	2.166
4	2.058	2.502
5	3.114	2.866
Delta	1.091	0.700
Rank	1	2

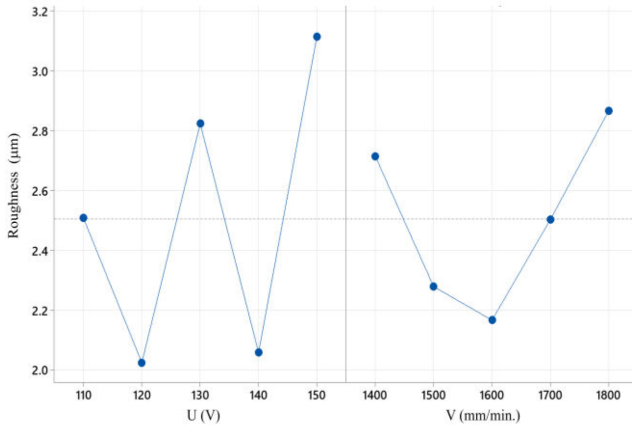

Figure 3. Average roughness corresponding to each level of input parameters.

From Figure 3, we can see that when the cutting voltage increases, the average roughness initially decreases and reaches the lowest value of 2.023 µm at U=120V, then when the voltage continues to increase, the average roughness obtained tends to increase. Similarly, when the cutting speed increases, the average roughness initially decreases and reaches the lowest value of 2.166 µm at V=1600 mm/minute, then when the cutting speed continues to increase, the average roughness obtained tends to increase. These results are consistent with the results published by Salonitisa when conducting research on 15mm thick steel plates [3].

IV. CONCLUSION

In this study, experiments were conducted on a CNC plasma cutting machine with 5mm thick SS400 steel plate, the quality of the cut was evaluated through surface roughness. The minimum surface roughness achieved was 1.5 µm corresponding to the case of 120V cutting voltage and 1700 mm/min cutting speed. The results showed that cutting voltage is the main parameter affecting the quality of the cut and the cutting mode to achieve the best cut quality is U=120V and V=1600 mm/min.

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