ELECTROCHEMICAL ENGRAVING OF THIN-WALLED SUS304 WORKPIECE

KHẮC ĐIỆN HOÁ CHI TIẾT THÉP KHÔNG GỈ CÓ THÀNH MỎNG

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ABSTRACT

Engraving is a prime importance operation to allow the identification of nearly all products in everyday life. In this study, the electrochemical engraving method is used to mark information on thin-walled SUS304 name cards (0.5 - 1mm in thickness). The relationships between the processing parameter inputs (DC current (I(A)), machining time (t(s)), and electrolytic concentration (C(%)) and criteria output (surface roughness (R_a)) were developed using the Box-Wilson experimental model to determine the optimal values of the processing parameters. The results showed that machining time (t(s)) is the most affected factor, and the optimal technological parameters are (I = 84A, C = 6.775%, t = 105s). The researched results will be the basis for selecting technological parameters when engraving similar materials in mass production conditions.

Keywords: *Advanced machining processes; electrochemical machining; name card; central composite design; stencil.*

TÓM TẮT

Khắc là một nguyên công quan trọng để cho phép nhận dạng hầu hết các chi tiết gia công và sản phẩm trong đời sống. Trong nghiên cứu này, phương pháp khắc điện hoá được sử dụng để khắc các thông tin trên danh thiếp mỏng làm bằng vật liệu inox (chiều dày 0,5 - 1mm). Mối quan hệ giữa các thông số công nghệ đầu vào (bao gồm cường độ dòng điện (I(A)), thời gian khắc (t(s)) và nồng độ dung dịch khắc (C(%)) và hàm mục tiêu đầu ra (nhám bề mặt (R_a)) được xây dựng theo ma trận quy hoạch Box-Wilson để xác định các thông số đầu vào tối ưu. Kết quả cho thấy thời gian khắc t(s) có ảnh hưởng lớn nhất đến chất lượng bề mặt khắc và chế độ gia công tối ưu là (I = 84A, C = 6,775%, t = 105s). Kết quả nghiên cứu sẽ là căn cứ để lựa chọn các thông số công nghệ khi khắc các vật liệu tương tự trong điều kiện sản xuất hàng loạt.

Từ khóa: *Các phương pháp gia công đặc biệt; gia công điện hóa; tấm danh thiếp; quy hoạch tâm hỗn hợp (CCD); khuôn khắc.*

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1. INTRODUCTION

Stainless steel is not only wear-resistant, anti-oxidation, and durable, but also has fine art and delicate elegance. Thus, stainless steel is widely used in civil and industrial industries such as: architecture; construction; automobile; chemical industry; houseware; food-medical equipment and stationery [1]. In the field of stationery, the current business name card, in addition to conveying information, also requires higher aesthetics than ever before, thereby helping to enhance the status of users. Therefore, there is a great demand in using stainless steel as a new material for business name cards. Among the existing stainless steel brands, SUS304 stainless steel has durability, good gloss, moderate price, so it is suitable for thin-walled name cards.

Generally, engraving is a machining process of making a symbol on a part to attain its identification. Engraving is mostly applied on the finished part at the end of the process of manufacturing the part, with the purpose of forming a permanent trace on its surface in order to make it readable and recognizable. A clear engraving not only records variable specification and specialized data of the part (e.g., alphanumeric characters, barcode, batch numbers, location numbers, serial number, and the like), but also it promotes advertising. Engraving methods can be done in different ways, such as swab printing, ink printing, screen printing/silk-screen printing/serigraph, labelling, mechanical engraving (e.g., CNC milling, dot peen, metal stamp), laser engraving (LE) and electro-chemical engraving (ECE). All of these have particular advantages and disadvantages. Labelling and printing-based engraving methods provide direct product marking, but disadvantage of these methods is the fact that marks are not long lasting because they can be damaged or ink can fade. Recently, LE and ECE have been developed in various researches [2, 3]. LE is a well-known technique to engrave on the product's surface by utilizing the thermal effect induced by the laser with high energy to make the marking region melt locally and obtain the designed marking shape. However, there exist some disadvantages in the LE, such as the oxidation of material and the presence of the remelted layer. Furthermore, changes in color of the surface of the product and the possibility of toxic vaporization during LE and high cost of equipment are also two of the shortcomings. ECE is a kind of electrochemical machining process using a small amount of electric current and an electrolyte to engrave a permanent mark on the surfaces of high hardness and high strength materials. ECE method has the advantage of ease of application, no cause of distortion on the sheet metal, cost effectiveness, no residual stress and no heat-effected zone.

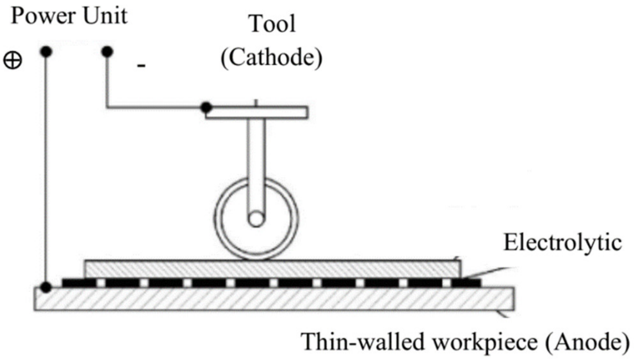


Figure 1. A schematic diagram of electrochemical machining process

In this study, the so-called thin-walled stainless steel is defined as a kind of sheet specimen with its thickness of 0.5-1 mm. There is a great demand on the creation of textures, patterns, logos, labels, signs of product recognition, number, name tag or other information on the thin walled-products (e.g., metal business cards). The machinability and precision of the thin-walled stainless steel are affected by the following factors [4]: precision of the cutting machine, thermal deformation of the tool, tool wear and deformation of the workpiece. From the said factors, the deformation of the workpieces is the most important factor affecting the machining accuracy, due to the poor rigidity of the thin-walled stainless steel sheet and clamping deformation. For this reason, conventional engraving methods including mechanical engraving and/or LE cannot be practically applied to thin-walled sheets, due to mechanical and thermal deformation [5]. Therefore, the ECE method is used for etching cavities with a depth of 0.01 - 0.2mm to form drawings and inscriptions on thin-walled SUS304 workpiece. The dynamics of change in the shape of the cavities formed during ECE on the different neutral salt solutions has been examined. Three input parameters used in ECE comprising current I(A); machining time t(s) and electrolyte concentration C(%) to obtain the mark clearance quality. Based on experimental results, the optimum electrolyte compositions and treatment modes have been determined.

2. MATERIALS AND METHODS

2.1. Electrochemical engraving

ECE system is a process in which a permanent mark is made in a conductive metal. It requires a low voltage power source, stencil, felt pad, and conductive liquid (or electrolyte) [6]. First, a power source is attached to the electrode and the workpiece. Current varies from 0 - 100A depending on the stencil size and the line density. The depth of etch can be accurately controlled. The stencil is typed or prepared photographically on a special paper and fitted to a pad, damped with the electrolyte. The pad is then pressed against the workpiece to be engraved, during the application of a controlled voltage for a specified time. The electrolytic solution is pressed out through the contours of the stencil and reaches the surface of the sheet by means of the pressure of a tool. The required time for electrochemical etching is a function of the workpiece material and the applied current. The depth of the engraved surface is proportional to the time of machining. It should be noted that the surface of the workpiece must be cleaned before the stencil is placed and after finishing with a neutralizing solution.

2.2. Experiments and measurements

The experiment was conducted on an ECE machine (Trademark: ECM®MTA) with the basic configuration indicated in Figure 2. The machine can engrave alphanumeric symbols, barcodes, product codes, logos, textures, patterns or special symbols on any conductive materials.

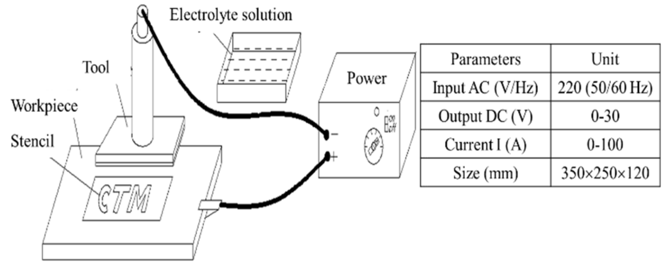
Plate cathode and workpiece anode were made of SUS304. The size of anode is 40mm (in width) x 60mm (in length) x 0.8mm (in height). The chemical composition of the workpiece is described in Table 1.

As for electrolyte, it should avoid the formation of a passive film on the anodic surface, so anions Cl^-, SO_4^{2-}, NO_3^-, ClO_3^-, OH^- are selected. On the other hand, Na^+ or Ka^+ cations are used to avoid cathode precipitation [7]. For optimal efficiency, an electrolyte solution must be selected suitable for the processing material. During experiments, several kinds of electrolyte solution were tested to determine which one is best for the mark quality on SUS304. Polymeric adhesive tape with rectangular cutouts with a size of 40 × 40mm was applied on the anode surface.

Digital camera (Model: Samsung Note 9, Korea) and microscope were utilized to capture and analyze the marks. Meanwhile, the surface roughness tester TR200 (Mitutoyo Corp.) with a resolution of 0.01µm was used to measure the surface roughness of the marks.

Table 1. Chemical compositions of SUS304 [8]

C	Si	Ni	Cr	P	S	N	Mn	Cu	Fe
0.042%	0.45%	8.09%	18.06%	0.045%	0.015%	0.058%	0.97%	0.02%	Bal.



Parameters	Unit
Input AC (V/Hz)	220 (50/60 Hz)
Output DC (V)	0-30
Current I (A)	0-100
Size (mm)	350×250×120

Figure 2. ECE machine

3. RESULTS AND DISCUSSION

3.1. Engraving Quality

On the basis of guides on electrolyte selection, 3 kinds of electrolytes (namely, Na_2SO_4, $Fe_2(SO_4)_3$, and NaCl) were chosen during ECE. As shown in Figure 3, through the surface smoothness and roughness of the marks, it is confirmed that Na_2SO_4 electrolyte solution creates marks on SUS304 with the best quality. Thus, Na_2SO_4 solution was further used in optimization experiments.


NaCl ($R_a = 3.050\mu m$) $Fe_2(SO_4)_3$ ($R_a = 0.715\mu m$) Na_2SO_4 ($R_a = 0.337\mu m$)

Figure 3. Engraving quality of different electrolytes

3.2. Development of an optimal experimental design

Two-level Box-Wilson Central Composite Design was employed to investigate the effects of 3 factors I(A), C(%), t(s) on the response (surface roughness of electrochemically engraved SUS304 sheet specimens). The significant variables like current, electrolyte concentration and machining time were chosen as the independent variables and designed as x_1, x_2, x_3, respectively, through the following Equation:

$$y_i = ax_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_{12}x_1x_2 + a_{13}x_1x_3 + a_{23}x_2x_3 + a_{11}x_{12} + a_{22}x_{22} + a_{33}x_{32} \quad (1)$$

The range of current I(A) is from 30 to 90, the electrolyte concentration C% is from 10 to 40 and the machining time t(s) is from 40 to 120. From that, experimental conditions determined by the Box-Wilson statistical design are presented in Table 2.

Table 2. The experimental range of variables

Numeric Factors	Independent parameters		
	Current I(A)	Concentration C%	Time t(s)
High level (+1)	90	40	120
Center point (0)	60	25	80
Low level (-1)	30	10	40
Random error component ε	30	15	40
"Start point" α	1.215	1.215	1.215
$\lvert\varepsilon\rvert.\alpha$	1.215×30 = 36.45 (round up 40)	1.215×15 = 18.225 (round up 20)	1.215×40 = 48.6 (round up 50)
Lower value	20	5	30
Higher value	100	45	130

In 15 trial experiments, the values of the variables are built as follows: I(A) ϵ {20, 30, 60, 90, 100} was coded as x_1; C(%) ϵ {5, 10, 25, 40, 45} was coded as x_2; t(s) ϵ {30, 40, 80, 120, 130} was coded as x_3. The designed experiments were carried out according to the designed parameters and the surface roughness of the samples as shown in Figure 4 were measured. Finally, the experimental results were summarized in Table 3.

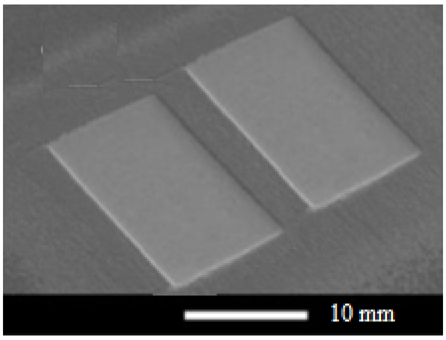


Figure 4. Samples for surface roughness measurements

3.3. Determination of regression equation

Based on the experimental results as depicted in Table 3, by performing algorithms to determine the coefficients in the regression equation according to the Box-Wilson orthogonal experimental design [9], the following equation is derived:

$$y_{Ra} = 0.606 - 0.034x_1 + 0.138x_3 + 0.214x_1x_2 + 0.064x_1x_3 - 0.071x_2x_3 - 0.051x^2_3 \quad (2)$$

3.4. The effects of process parameters on the surface roughness y_{Ra}

From regression equation (2), the effect of each processing variable on the surface roughness was determined as follows:

$$y_{Ra}(x_1, 1, 1) = 0.622 + 0.244x_1 \quad (3)$$

$$y_{Ra}(1, x_2, 1) = 0.808 + 0.723x_2 \quad (4)$$

$$y_{Ra}(1, 1, x_3) = 0.786 + 0.131x_3 - 0.051x_3^2 \quad (5)$$

Based on (2), (3), (4), it is found that the most effected factor variable is x_3 (i.e, machining time t(s)), followed by x_2 (i.e, concentration C(%)) and then x_1 (i.e, current I(A)).

- According to (3) because the coefficient of x_1 is a positive coefficient, so the relationship between x_1 and y_{Ra} is proportional to each other. Here, when x_1 varies from -1.215 to 1.215, y_{Ra} changes from small value to large value, that is, an increase in current leads to increase in roughness of surface.

- According to (4) because the coefficient of x_2 is positive, so the relationship between x_2 and y_{Ra} is proportional to each other. That is, when x_2 varies from -1.215 to 1.215, y_{Ra} also changes from the low value to high value.

- According to (5) when x_3 changes from -1.215 to 0, y_{Ra} value increases. In contrast, when x_3 changes from 0 to 1.215, y_{Ra} value decreases.

3.5. Optimization result

The developed models for the processing variables and y_{Ra} are optimized using the Box-Wilson gradient descent method. As a result, the extreme (minimum) values of the regression function can be obtained as follows: $y_{Ra(min)} = 0,309$ at $(x_1, x_2, x_3) = (0.797; -1.215; 0.626)$ corresponding to I = 84A, C = 6.775% and t = 105s.

Table 3. Experimental results

ND	Nº	Real variables			Coded variables										Results y_{Ra}
		I(A)	C(%)	t(s)	x_0	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	x_1'	x_2'	x_3'	
2^k	1	30	10	40	+	-	-	-	+	+	+	0.27	0.27	0.27	0.811
	2	90	10	40	+	+	-	-	-	-	+	0.27	0.27	0.27	0.371
	3	30	40	40	+	-	+	-	-	+	-	0.27	0.27	0.27	0.322
	4	90	40	40	+	+	+	-	+	-	-	0.27	0.27	0.27	0.652
	5	30	10	120	+	-	-	+	+	-	-	0.27	0.27	0.27	1.002
	6	90	10	120	+	+	-	+	-	+	-	0.27	0.27	0.27	0.732
	7	30	40	120	+	-	+	+	-	-	+	0.27	0.27	0.27	0.545
	8	90	40	120	+	+	+	+	+	+	+	0.27	0.27	0.27	0.845
2k	9	100	25	80	+	1.215	0	0	0	0	0	0.75	- 0.73	- 0.73	0.578
	10	20	25	80	+	-1.215	0	0	0	0	0	0.75	- 0.73	- 0.73	0.515
	11	60	45	80	+	0	1.215	0	0	0	0	- 0.73	0.75	- 0.73	0.698
	12	60	5	80	+	0	-1.215	0	0	0	0	- 0.73	0.75	- 0.73	0.430
	13	60	25	130	+	0	0	1.215	0	0	0	- 0.73	- 0.73	0.75	0.578
	14	60	25	30	+	0	0	-1.215	0	0	0	- 0.73	- 0.73	0.75	0.434
n_0	15	60	25	80	+	0	0	0	0	0	0	- 0.73	- 0.73	- 0.73	0.941

Table 4. The verified results of optimum parameters.

Measurement / Sample	1st (μm)	2nd (μm)	3rd (μm)	Real value (μm)	Calculated value (μm)	Error
1	0.295	0.310	0.298	0.301	0.309	2.59%
2	0.373	0.246	0.259	0.293	0.309	5.18%
3	0.291	0.375	0.299	0.322	0.309	4.04%
Mean value				0.305	0.309	3.94%

Figure 5. Logo marking on thin-walled product

To verify the above calculation results, three samples were machined by the optimal technological parameters (I = 84A, C = 6.775%, t = 105s) with the material and machine tool unchanged. The verified results were summarized in Table 4. It can be seen that the average real value of surface roughness is 0.305μm, with an error of 3.94% compared to the calculated value. This result proves the correctness of the research method. Based on the above-mentioned optimal parameters, a required logo was marked on an industrial thin-walled product as illustrated in Figure 5.

4. CONCLUSION

ECE was performed on thin-walled stainless steel. The conclusions of this research can be listed as follows:

1. For thin-walled SUS304 workpiece engraving, the electrochemical method is the most convenient because of its ease of application, cost effectiveness, high accuracy and resolution.

2. The relationship between 3 factors of I(A), C(%), and t(s) and the surface roughness response was investigated using Box-Wilson experimental design. The optimal value of technological parameters (I = 84A, C = 6.775%, t = 105s) is determined as the best conditions for engraving thin-walled 304 stainless steel. The researched results are the basis for applying the optimal technology regime when etching similar materials by electrochemical method under mass production conditions.

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THÔNG TIN TÁC GIẢ

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