



Experimental Investigation on Electrochemical Grinding (ECG) for Stainless Steel 316

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ABSTRACT

This research focuses on material removal rate (MRR) and surface roughness during electrochemical grinding (ECG) for stainless steel 316. The effect of applied current, electrolyte concentration, gap size and spindle speed on machining performances has been studied. Where applied current used are (10, 20, 30, 40) A, electrolyte concentration used (100, 150, 200, 250) g/l, gap size used (0.2, 0.3, 0.4, 0.5) mm and spindle speed used (75, 150, 180, 280) rpm. Through the Taguchi design based experimental study the characteristic features of the ECG process are discussed. Where the maximum MRR can be obtained at 40 A of the current, 250 g/l of the concentration, 0.2 mm of the gap and 180 rpm of spindle speed. The best surface roughness can be obtained at 10 A of the current, 200 g/l of the concentration, 0.4 mm of the gap and 280 rpm of spindle speed..

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1. Introduction

Electrochemical grinding (ECG) is one of the hybrid electrochemical processes. It consists of a combination of the mechanical grinding process and electrochemical machine (ECM). ECG procedure to removal metal requires a conductive grinding wheel with metal-bonded in which a negative charge as a cathode, workpiece with a positive charge as an anode, connected to DC power source and electrolyte solution in the gap between tool and workpiece. The electrolyte solution consists of water mixed with salt. The heat generated in this procedure is much less as compared to the traditional grinding process and because most of the metal removal process occurs by electrolytic dissolution so, no thermal residual stresses and heat-affected zone are obtained during the ECG procedure [1]. The metal removal occurs in this process by electro-chemical reaction, which removes about (90% - 95%), while mechanical action is responsible for removal (5% - 10%) [2]. Electrolysis is performed at low voltage (5-25 V) so that the quality of the function is not affected by the spark

[3]. ECG process can be applied in manufacture hard alloys such as Tungsten carbide, stainless steel, and metal-ceramic hard alloy of WC-Co groups and obtain the best MRR and surface roughness compared with other finishing processes [4-5]. Maksoud [6] studied the effect of voltages and the electrolyte flow rate on MRR also compared the ECG process with the traditional grinding process, found the MRR increases with voltage increased. Roy [7] Evaluated the effect of different voltages on surface roughness, where the applied voltages were (2-15) V, Found the best surface roughness was 0.8 μm at 15V. Goswami [8] focused on studying the effect of concentration of electrolyte, applied voltage, electrolyte flow rate and depth of cutting on MRR and surface roughness during ECG of the Al₂O₃/Al interpenetrating phase compound. Molla [9] focused on the study of voltages, spindle speed and concentration of electrolyte and its effect on surface roughness by using the Taguchi method to improve ECG parameters. Bhandari [10] studied the effect of cutting speed and voltages on MRR and surface roughness, found that the MRR increases with the cutting speed and voltages were 0.89908 g/min, the best surface roughness was 0.789 μm at 16 m/s and 12.0487 V. In this research, the ECG process used stainless steel 316 for Experiments to study the effect of applied current, electrolyte concentration, gap and spindle speed on MRR and surface roughness.

2. Experimental Procedures

Figure 1 shows a schematic diagram of ECG. When the machining conditions are applied, the rotary wheel is perpendicular to the workpiece.

In this research, the cylindrical diamond-grinding wheel a metal-bonded is chosen as a cathode tool as shown in Figure 2, and choose stainless steel 316 as anode workpiece with chemical composition measured are shown in Table 1. The dimensions of the workpiece are (60 × 40 × 2) mm³.

Table 2 shows the machining conditions used in this work. Taguchi design was used for this experiment.

MRR was measured by the weighted samples before and after the experiment by Sensitive Balance (BAS31, Boeco, Germany). Where the material removal rate was determined by

$$MRR = \frac{w_b - w_a}{t}, \text{ (g/min)} \quad (1)$$

Where: w_b = the weight of workpiece before ECG operation, g

w_a = the weight of workpiece after ECG operation, g

t = the time of operation, min

The surface roughness was measured after machining by using device MarSurf PS1.

To achieve the highest productivity in the ECG process, the highest MRR is desired and therefore MRR can be classified as "the biggest is the best", where the signal to noise ratio was calculated in this case as follows:

$$\text{S/N ratio of MRR} = -10 \log \frac{1}{n} \left(\sum_{i=1}^n \frac{1}{y^2} \right) \quad (2)$$

While less surface roughness is always better in the production environment, therefore the surface roughness was classified as "smaller is better" and the signal to noise ratio was calculated in this case as follows:

$$\text{S/N ratio of Ra} = -10 \log \frac{1}{n} \left(\sum_{i=1}^n y^2 \right) \quad (3)$$

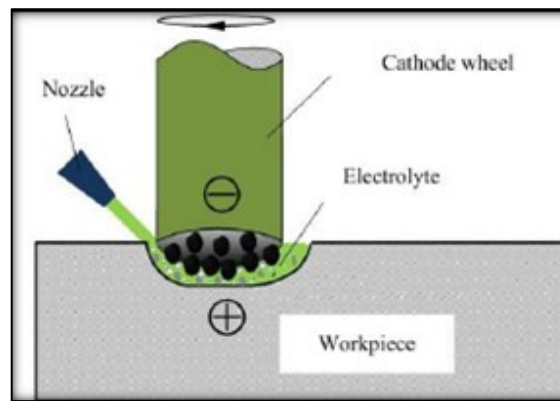


Figure 1: Diagram of ECG [11]

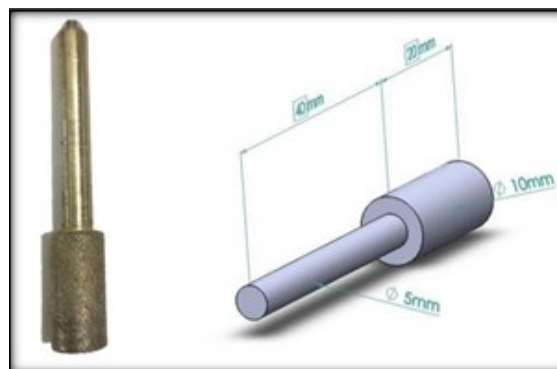


Figure 2: Cylindrical grinding wheel

Table 1: Chemical composition of stainless steel 316 H

	C%	Mn%	Si%	P%	S%	Cr%	Mo%	Ni%
alloy	0.05	1.76	0.39	0.03	<.0005	18.73	0.28	8.69
	7	9	1	5			4	
AISI	0.04	2.0	0.75	0.45	0.03	16-18	2 - 3	10-14

Table 2: Machining conditions

Parameter	Value
Electrolyte	NaCl
Applied current (A)	10, 20, 30, 40
Concentration (g/l)	100, 150, 200, 250
Gap (mm)	0.2, 0.3, 0.4, 0.5
Spindle speed (rpm)	75, 150, 180, 280

3. Results and Discussion

Based on the experimental result presented in Table 3, the effect of different process parameters on MRR and surface roughness was analyzed by Analyses Of Variance (ANOVA). The main purpose of ANOVA is to investigate the parameters designed and refer to the parameters, which greatly affect the quality property.

I. Results for MRR

Figure 3 shows the differences in MRR (g/min) with applied current, electrolyte concentration, gap and spindle speed based on the experimental results shown in Table 3. It is noted that MRR is the maximum is 0.57466 g/min at a 40 A of current, the concentration of 250 g/l, 0.2 mm of gap and spindle speed of 180 rpm.

Table 4 shows the ANOVA and “F-test” values of contribution. It is noted the current is the most significant parameter for maximum MRR and gap size is the next significant parameter for maximum MRR and then electrolyte concentration.

It was observed that the applied current and the gap had a significant highest effect on MRR; while the concentration of electrolyte and spindle speed had little effect on material removal rate. MRR increased by increasing the current and concentration of the electrolyte while it was decreased with the increasing of the amount of gap. Increasing the speed to a certain level leads to increase MRR and then begins to decrease with the continued increase of spindle speed; it is because when the speed increases from (180 to 280) rpm with used constant other parameters lead to reduce in reaction dissolution.

Table 3: Taguchi L_{16} orthogonal array and experimental result

Exp. no.	Concentration (g/L)	Current (A)	GAP (mm)	Speed (RPM)	MRR (g/min)	Ra (μm)
1	100	10	0.2	75	0.09906	0.1285
2	100	20	0.3	150	0.23532	0.3820
3	100	30	0.4	180	0.26620	0.5580
4	100	40	0.5	280	0.32234	1.3610
5	150	10	0.3	180	0.10052	0.1470
6	150	20	0.2	280	0.26572	1.0590
7	150	30	0.5	75	0.22668	0.4141
8	150	40	0.4	150	0.36380	2.1825
9	200	10	0.4	280	0.10062	0.0595
10	200	20	0.5	180	0.18732	0.2560
11	200	30	0.2	150	0.28616	0.2060
12	200	40	0.3	75	0.36144	1.1420
13	250	10	0.5	150	0.10172	0.0640
14	250	20	0.4	75	0.21838	0.1870
15	250	30	0.3	280	0.26732	0.6471
16	250	40	0.2	180	0.57466	0.7310

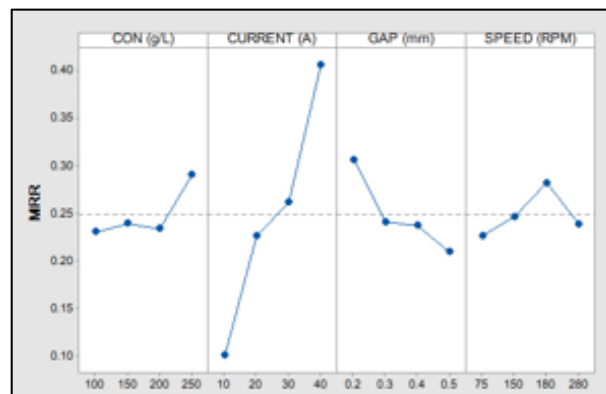


Figure 3: Mean graph for MRR

Table 4: Analyses of Variance for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F
Con.	3	0.0095	0.0095	0.0031	1.24
Current	3	0.1889	0.1889	0.0629	24.52
Gap	3	0.0202	0.0202	0.0067	2.62
Speed	3	0.0068	0.0068	0.0022	0.89
Residual Error	3	0.0077	0.0077	0.0025	
Total	15	0.2332			

II. Results for surface roughness (Ra)

Figure 4 shows variations in surface roughness with applied current, electrolyte concentration, gap, and spindle speed. From Table 3, it appears that the lowest surface roughness can be obtained is

0.0595 μm at 10 A of the current, 200 g/l of the electrolyte concentration, 0.4 mm of gap and spindle speed of 280 rpm.

Table 5 shows the ANOVA and “F-test” values of contribution. It is noted the current is the most significant parameter for minimum Ra and electrolyte concentration is the next significant parameter for minimum Ra and then spindle speed.

It is observed from Figure 4 that the concentration of the electrolyte, the current and the gap have a significant effect on surface roughness while spindle speed has less effect on surface roughness, where it is noted that their effect is fluctuating on the surface roughness. The surface roughness increases with the increase in the applied current; because when current increase, the temperature increases in the reaction zone during the process, which generates cracks in the surface of the workpiece. The surface roughness decreases with the increased concentration of the electrolyte and reduces the gap, while the effect of spindle speed is low on surface roughness.

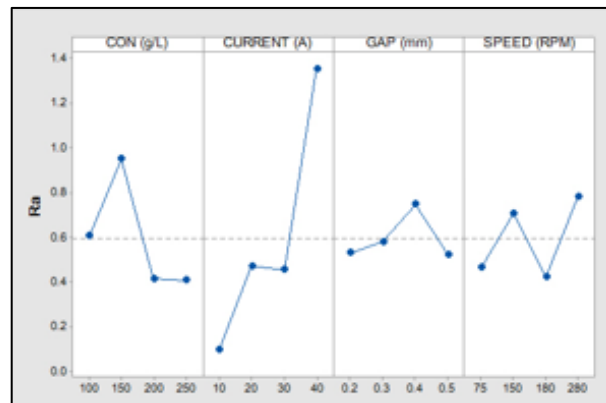


Figure 4: Mean graph for Ra

Table 5: Analyses of Variance for Ra

Source	DF	Seq SS	Adj SS	Adj MS	F
Con.	3	0.7759	0.7759	0.25862	1.77
Current	3	3.4246	3.4246	1.14154	7.82
Gap	3	0.1297	0.1297	0.04323	0.30
Speed	3	0.3739	0.3739	0.12465	0.85
Residual Error	3	0.4377	0.4377	0.14591	
Total	15	5.1418			

4. Conclusions

It is observed from Figure 4 that the concentration of the electrolyte, the current and the gap have a significant effect on surface roughness while spindle speed has less effect on surface roughness, where it is noted that their effect is fluctuating on the surface roughness. The surface roughness increases with the increase in the applied current; because when current increase, the temperature increases in the reaction zone during the process, which generates cracks in the surface of the workpiece. The surface roughness decreases with the increased concentration of the electrolyte and reduces the gap, while the effect of spindle speed is low on surface roughness.

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