Influence of Wire Electrical Discharge Machining (WEDM) process parameters on surface roughness

Mohammad Yeakub Ali[1], Asfana Banu[1], Mazilah Abu Bakar[2]

[1]Department of Manufacturing and Materials Engineering, International Islamic University Malaysia, PO Box 10, 50728 Kuala Lumpur, Malaysia
[2]Department of Mechanical Engineering, Politeknik Sultan Haji Ahmad Shah, 25350 Semambu, Kuantan, Pahang, Malaysia

Email: mmyali@iium.edu.my

Abstract. In obtaining the best quality of engineering components, the quality of machined parts surface plays an important role. It improves the fatigue strength, wear resistance, and corrosion of workpiece. This paper investigates the effects of wire electrical discharge machining (WEDM) process parameters on surface roughness of stainless steel using distilled water as dielectric fluid and brass wire as tool electrode. The parameters selected are voltage open, wire speed, wire tension, voltage gap, and off time. Empirical model was developed for the estimation of surface roughness. The analysis revealed that off time has a major influence on surface roughness. The optimum machining parameters for minimum surface roughness were found to be at a 10 V open voltage, 2.84 µs off time, 12 m/min wire speed, 6.3 N wire tension, and 54.91 V voltage gap.

1. Introduction

Electrical discharge wire cutting, more commonly known as wire electrical discharge machining (WEDM) is a specialized thermal machining process capable of accurately machining parts with varying hardness or complex shapes, which have sharp edges that are very difficult to be machined by the main stream machining processes. At present, WEDM is a widespread technique used in industry for high-precision machining of all types of conductive materials such as metals, metallic alloys, graphite, or even some ceramic materials, of any hardness [1], [2]. The degree of accuracy of workpiece dimensions obtainable and the fine surface finishes make WEDM particularly valuable for applications involving manufacture of stamping dies, extrusion dies, and prototype parts. Without WEDM, the fabrication of precision workpiece requires many hours of manual grinding and polishing [3]. Apart from that, WEDM is widely used in the area of production of aerospace parts micro gas turbine blades and electronic components [4].

WEDM is based on electrical discharge machining process, which is also called electro-erosion machining process. When the gap voltage is sufficiently large (i.e reaches the breakdown voltage of dielectric fluid), high power spark is produced, where the temperature increases up to 10,000 °C and allows the removal of metal from the machining area [5], [6]. In WEDM, performance measures are the indicators that are used to observe or to assess the quality of finished products or parts, whereas, the process parameters are the variables that influence the machining process. The most substantial performance measures in WEDM are surface finish, material removal rate, and kerf width. Surface

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roughness is used to control the quality of the finished part while kerf width is used to determine the accuracy of dimension and material removal rate for economic purposes. According to previous research, the surface roughness improves when the pulse duration and the discharge current decreases [7]. All of these performance measures are usually affected by the process parameters such as pulse on-time, open voltage, servo voltage, wire feed, dielectric pressure, wire tension, and etc. These parameters have the ability to improve the machined surface quality with less cracks and surface damages [8]. Hence, the objective of this paper is to investigate the influence of WEDM process parameters on surface roughness of stainless steel using distilled water as the dielectric fluid and brass wire as the tool electrode.

2. Experimental procedures

The experimental investigation was performed using the Mitsubishi FX10K CNC Wire EDM. The workpiece material, which was stainless steel S304, was prepared in desired dimension of 150 mm × 8 mm ×10 mm with flat surface finish. Stainless steel is widely used almost in all industrial applications, is accounted for approximately 50% of the world's stainless steel production and consumption. Because of its aesthetic view in architectures, resistance against corrosion and chemicals, high hardenability, and well mechanical property, it becomes the most preferred material [7], [9]. Brass wire with 0.2 mm diameter was used as the tool electrode whereas distilled water as the dielectric fluid. The experimental parameters are listed in table 1. The parameters were selected based on the type of machining material, tool material, height of the workpiece, and the capability of the machine. The experiments were designed using the Taguchi's L_{16} orthogonal array statistical model. The controlled parameters were voltage open, wire speed, wire tension, voltage gap, and off time. Mitutoyo Surftest (SV-514) was use to measure the surface roughness (R_a). The tester used a cut-off length of 2 mm and evaluation length of 0.8 mm. The tester uses Surfpak V4.10 (2) software with a resolution of 0.01 μm and stylus speed of 0.10 mm/sec. Measurements of R_a were repeated three times, and the average of the R_a was calculated. The experimental results are tabulated in table 2. The results are analysed using the signal to noise (S/N) ratio and analysis of variance (ANOVA) approach.

3. Results and Discussion

3.1 Signal to Noise (S/N) ratio

The S/N ratio according to Taguchi method is the ratio of signal to noise where signal represents the desirable value and noise represents the undesirable value. The S/N ratio for the experiments conducted is shown in table 2 meanwhile the mean of S/N ratio for R_a is presented for four level are tabulated in table 3. According to Taguchi method, minimizing average R_a would be better for precision manufacturing. Hence, "smaller-the better" type problems would give a smaller values for average R_a in order to get a better quality of finish parts [10]. Based on table 3, it was found that S/N ratio for R_a decreases when the wire speed, wire tension, and voltage gap are at level 4. The wire vibration tends to reduce when the wire tension increases which helps the surface roughness to improve [11]. Meanwhile, the S/N ratio for R_a increases when the off time is at level 4 and level 3 for voltage open. Voltage open should be kept as low as possible in order to get a better surface roughness. It is to avoid powerful explosion to occur which can cause deep crater on the machined surface and resulting with poor surface quality at the machined area [11-12].

3.2 Analysis of variance (ANOVA)

An empirical model as expressed in Eq. 1 is developed by ANOVA. Based on table 4, the model F-value of 102.38 implies that the model is significant. There is only a 0.14% chance of noise that could occur in the model F-value. The prob>F values less than 0.0500 indicates that the model terms A (voltage open), B (off time), E (voltage gap), AB (voltage open and off time), AC (voltage open and wire speed), BD (off time and wire tension), BE (off time and voltage gap), CD (wire speed and wire tension), CE (wire speed and voltage gap), and DE (wire tension and voltage gap) are significant. The most significant factor that affects the R_a is B with 77.57 F-value. However, values that are greater

than 0.1000 indicates the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), then the model reduction may improve the model. Factors C and D are the most uninfluenced factors since their prob>F are 0.5508 and 0.9052 respectively. Nevertheless, when factor C interact with factor A, D, and E, the model terms becomes significant. Hence, it means that factor C cannot be removed from the hierarchy, even though it is not significant if it is stand-alone. It goes same with factor D, where the model terms become significant when it interacts with factor B, C, and E. The Predicted R^2 of 0.8133 is in reasonable agreement with the Adjusted R^2 of 0.9878. Adequate precision measures the signal to noise ratio, where the ratio greater than 4 is desirable. The ratio of 44.649 indicates that the signal is adequate. This model can be used to navigate the design space.

Table 1. Experimental parameters

		Level			
Control Parameters	**Factors**	**I**	**II**	**III**	**IV**
Voltage open (V)	A	10	12	14	16
Off time (μs)	B	1	2	3	4
Wire speed (m/min)	C	6	8	10	12
Wire tension (N)	D	6	7	8	9
Voltage gap (V)	E	40	45	50	55
Fixed Parameters:					
Workpiece material	Stainless steel S304				
Tool electrode	Brass wire (Ø 0.2 mm)				
Dielectric fluid	Distilled water				

Table 2. Experimental result

	Parameters					Response	
Run	Voltage open (V)	OFF time (μs)	Wire speed (m/min)	Wire tension (N)	Voltage gap (V)	Average surface roughness R_a (μm)	S/N value Average surface roughness
1	14.00	3.00	6.00	7.00	55.00	3.22	-10.1571
2	10.00	3.00	10.00	8.00	50.00	3.13	-9.9109
3	14.00	4.00	8.00	6.00	50.00	2.05	-6.2351
4	16.00	3.00	8.00	9.00	40.00	2.79	-8.9121
5	12.00	3.00	12.00	6.00	45.00	3.45	-10.7564
6	12.00	2.00	6.00	9.00	50.00	3.11	-9.8552
7	14.00	2.00	12.00	8.00	40.00	3.44	-10.7312
8	16.00	4.00	6.00	8.00	45.00	2.96	-9.4258
9	16.00	2.00	10.00	6.00	55.00	2.73	-8.7233
10	10.00	2.00	8.00	7.00	45.00	2.72	-8.6914
11	10.00	4.00	12.00	9.00	55.00	3.86	-11.7317
12	16.00	1.00	12.00	7.00	50.00	3.51	-10.9061
13	12.00	4.00	10.00	7.00	40.00	2.97	-9.4551
14	14.00	1.00	10.00	9.00	45.00	3.01	-9.5713
15	10.00	1.00	6.00	6.00	40.00	2.82	-9.0050
16	12.00	1.00	8.00	8.00	55.00	3.09	-9.7992

$$R_a = 3.755 + 0.831A - 1.063B + 1.949C - 2.314D - 0.199E - 0.096AB - 0.058AC + 0.206BD + 0.011BE - 0.035CD - 0.019CE + 0.044DE \quad (1)$$

Where, R_a = surface roughness (μm), A = voltage open (V), B = off time (μs), C = wire speed (m/min), D = wire tension (N), and E = voltage gap (V).

Table 3. S/N ratio means for R_a

Process parameters	S/N Ratio mean			
	Level 1	Level 2	Level 3	Level 4
Voltage open (V)	-9.8347	-9.9665	-9.1737	-9.4918
OFF time (μs)	-9.8204	-9.5003	-9.9341	-9.2119
Wire speed (m/min)	-9.6108	-8.4094	-9.4151	-11.0314
Wire tension (N)	-8.6799	-9.8024	-9.9668	-10.0176
Voltage gap (V)	-9.5258	-9.6112	-9.2268	-10.1028

Table 4. ANOVA for average R_a

Source	Sum of Square	Degree of Freedom (DF)	Mean Square	F Value	Prob>F
Model	2.56	12	0.21	102.38	0.0014
A	0.12	1	0.12	55.36	0.0050
B	0.16	1	0.16	77.57	0.0031
C	9.364E-004	1	9.364E-004	0.45	0.5508
D	3.491E-005	1	3.491E-005	0.017	0.9052
E	0.026	1	0.026	12.62	0.0380
AB	0.098	1	0.098	47.14	0.0063
AC	0.14	1	0.14	69.43	0.0036
BD	0.54	1	0.54	259.29	0.0005
BE	0.040	1	0.040	19.05	0.0222
CD	0.061	1	0.061	29.29	0.0124
CE	0.48	1	0.48	231.98	0.0006
DE	0.39	1	0.39	185.59	0.0009
Residual	6.256E-003	3	2.085E-003		
Cor Total	2.57	15			

Standard deviation	0.046	R^2	0.9976
Mean	3.05	Adjusted R^2	0.9878
Coefficient of variation	1.50	Predicted R^2	0.8133
Predicted residual error of sum of square (PRESS)	0.48	Adequate precision	44.649

3.3 Optimization and Verification

The ANOVA-based optimization was done in order to get the optimum values of the process parameters for minimum R_a. Minimum R_a (2.56 μm) can be achieved at 10 V voltage open, 2.84 μs off time, 12 m/min wire speed, 6.3 N wire tension, and 54.91 V voltage gap. Experiments were conducted to validate the results obtained from the optimization. Based on the experiment, the actual R_a (2.76 μm) was higher compared to the optimize R_a (2.56 μm) with maximum error of 7.81%. The percentage error for minimum Ra is relatively small which shows the empirical Eq. 1 is valid.

4. Conclusion

In this research, the influence of WEDM process parameters on the surface roughness of stainless steel (S304) using brass wire as the tool electrode and distilled water as the dielectric fluid has been investigated. Following conclusions are drawn from the experimental study:

1. From S/N ratio, it can be inferred that wire speed, wire tension, and voltage gap should be at the highest level, which is level 4 while voltage open and off time should be at level 3 and 4 respectively to obtain low surface roughness.
2. Based on ANOVA, the most significant factor that influences the surface roughness is off time.
3. The minimum surface roughness is found to be 2.56 μm at 10 V voltage open, 2.84 μs off time, 12 m/min wire speed, 6.3 N wire tension, and 54.91 V voltage gap which are considered to be the optimum process parameters for WEDM of stainless steel.
4. The predicted value and experimental R_a value is within 7.81% error.

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