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Effect of Machining Parameters on Surface Roughness and Metal Removal Rate for AISI 310 L Stainless Steel in WEDM

Muayad M. Ali *, Abbas F. Ibrahim

Production Engineering and Metallurgy Dept., University of Technology-Iraq, Alsina'a street, 10066 Baghdad, Iraq.

*Corresponding author Email: pme.19.13@grad.uotechnology.edu.iq

HIGHLIGHTS

- The used program Minitab 17. The workpiece material was used stainless steel 310 L
- zinc coated brass wire of 0.25mm diameter used as a tool
- Process input parameters wire feed, wire tension, servo voltage, TON and Toff.
- The output parameters surface roughness and metal removal rate.
- Experiments are designed and analyzed using the factorial design approach.

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ABSTRACT

Wire electrical discharge machining (WEDM) is a non-traditional machining process that is widely used in the machining of conductive materials. This paper presents the investigation on surface roughness and metal removal rate of stainless steel using the wire-cut EDM process. Process input parameters wire feed (WF), wire tension (WT), servo voltage (SV), pulse on time (TON) and pulse off time (Tuff), and the output parameters surface roughness and metal removal rate. The work piece material was used stainless steel 310 L, zinc-coated brass wire of 0.25mm diameter used as a tool and distilled water is used as dielectric fluid. ANOVA used to measure and evaluate the relative importance of different factors. Experiments are designed and analyzed using the factorial design approach. The experimental results revealed that the most important machining parameter of the pulse of time has the most influence on the metal removal rate and the surface roughness. The maximum best metal removal rate is (0.052277 g/min). When the values are somewhat medium range, they are the best and the wire does not break at this range. Wire feed (7m/min), wire tension (7 kef), servo voltage (30 V), TON (30 sic), Tuff (30 sic). The expected values and measured values are well-matched as observed by additional confirmation experiments.

1. Introduction

Wire electrical discharge machining is a nontraditional electro thermal machining method that is controlled by a factor processing parameters such as pulse duration, pulse interval, current, voltage, wire tension, wire feed, and so on. The setting of input parameters has a dynamic effect on output parameters like material removal rate, surface finish, hardness, and wear resistance for optimal machining efficiency [1]. In the presence of dielectric, electrical energy is used to extract metal by producing electrical sparks that occur between the electrodes, the wire cut, and the work piece [2]. WEDM is a special feature of electrical machining that uses an electric, electric, conductor electric wire electrode which is continuously moving. The removal of metal occurs as a result of the wire spark erosion [2]. WEDM is probably the most inspiring and comprehensive business method of the last 50 years and it has many advantages to achieve. In spite of the hardness, it can machine whatever is electrically conductive since the machining is automatically completed to allow Wire EDM to give engineers more scope in the design and additional production control. It doesn't rely on special skill levels or many tools with different tolerances and geometry [3]. The importance of wire cut machining is that it has the ability to machine the work piece material with a high degree of dimensional precision while avoiding any mechanical contact between the wire electrode and the work piece. As a result, good surface finishes are obtained, minimizing finishing procedure time [4]. At high TON and IP values, the surface roughness is observed to be low [5 most influential electrical pulse parameter, TON and IP, have a major impact on wire EDM machining efficiency since their production values are proportional to discharge energy, which affects a material melting and vaporization during machining [6]. Because of its ease and versatility in machining complex geometrical shapes, wire EDM is

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common. Because of the high temperatures used in the wire EDM process [7]. The goal of experiment design is to achieve higher manufacturing production with the required precision [8]. The goal of this study is to study five process parameters, wire feeding, wire tension, servo voltage, TON and Tuff on the roughness of surface and metal removal rates. The work piece metal stainless steel 310 L using ANOVA variance analysis on surface roughness (SR) and metal removal rate (MRR) for the most pulse on-time effect. This process's experimented and expected values are nearly identical when using the Minilab17 program. Figure 1 shows the wire EDM process.

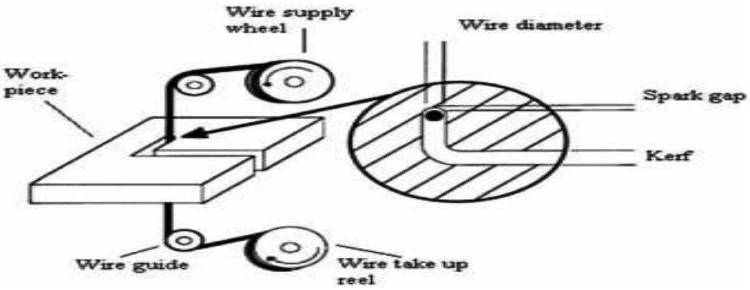

Figure 1: Wire-EDM Process [9]

In Basil Kuriachen, et al. [10] they worked on two phases of complete factor techniques used in Alloy of titanium (Ti-6Al-4V) wire electric discharge machining of surface roughness to model and predict. As a measured response variable after automatic processing. The surface roughness, TON, Tuff, SV, the input parameters were dielectric flushing pressure. The level of significance of the WEDM cutting coefficients on the surface using the study of contrast method. Roughness was calculated by (ANOVA). A mathematical relationship is formed between the roughness of the surface of the work piece and the WEDM cutting parameters. This mathematical model can be used without any experiments to test surface roughness. D.Sudhakara and G.Prasanthi [11] optimization of operation parameters (TON, Tuff, SV, IP, wire voltage and water pressure) of WEDM with Surface Roughness Performance response during machining VANADIS 4e Experiments on Mitsubishi WEDM and the Taguchi process were used to evaluate the best variables for metallurgical cold work steel tool. Pulse on time Following Time The voltage set by the spark gap had a major effect on the SR. Wire feed and Pulse time off had almost no effect on MRR. J. Singh, [12] paper explores the impact of various parameters of the WEDM process such as TON, Toff, SV, IP, dielectric flow rate, wire-speed, and wire voltage on different process response parameters such as metal removal rate (MRR) and surface roughness (Ra). The wire wear rate (WWR) and growth metal associated with the wire electrode work. Brass wire is commonly used as an In WEDM, as a wire electrode. The greater the current value, the greater the intensity of the spark, and the result is a high rate of metal removal. By reducing both the Surface roughness can be enhanced by increasing discharge current and pulse duration. The ratio of wire wear is increased by the increasing pulse length circuit voltage, whereas it is decreased by the increasing wire speed. As opposed to commonly used brass wire and zinc-coated wire. B. K. Lodi, et al. [13] CNC WEDM is commonly used in the aerospace, military industry, mound making, precision, electrical components machinery and components industries. The method Taguchi is used in WEDM to optimize machining parameters for the desired roughness of surface the machining response. The current work optimizes the cutting parameters of TON, Tuff, IP and WF in WEDM. In addition, the essential values of the parameters are Where to find the S/N ratio for Ra's efficient efficiency. The effect variables on Ra are pulse length and peak current with TON and IP, surface roughness increases. The most important Ra parameters were found in ANOVA.

2. Measurement of output parameters

2.1 Measurement of surface roughness

Measurement of surface roughness (SR) on the machined surface was carried out in various areas. The last surface roughness values calculated by the grade of the micrometer were obtained by the average. Is measured in micrometers in this work. It's a common metric for determining surface roughness. Ra was measured using a Maher Federal Company profiling meter, style Pocket surf. To determine the Ra, the probe scans the surface and compares peaks and valise. The probe movement was digitally displayed during the trace. As shown in Figure (2).

Figure 2: Surface roughness measuring device

2.2 Measurement of metal removal rate

The work piece weight was measured with an electronic weight balance before and after service (Denver instrument). It is an electrical instrument with a high resolution (0.001 g). The measurement range is (0.1-210 grams). The MRR was measured using (eq. 1) before and after cutting, the weight of the work pieces and the period determined by the sections.

- The MRR is the ratio of work piece weight difference prior to and beyond the cutting into the time of cutting. It was computed via this equation [14]

$$MRR = \frac{\text{weight of material removed from the workpiece}}{\text{machining time}} \tag{1}$$

$$\mathrm{MRR} = \frac{(\mathrm{WPVB} - \mathrm{WPWA})}{MT}, (g/min) \tag{2}$$

Where: MRR=the metal removal rate in (g/min).
$WPVB$= The work piece weight before the cutting in grams.
$WPWA$= The work piece weight after the cutting in grams.
MT= the time of machining (min).

3. Experimental procedure

The cutting method was carried out in the training center and laboratories in the turning workshop on the 4-axis Smart DEM (ELEKTRA DEM 400 A) EL PULSE 5 wire cutting machine. In these tests, zinc-coated brass wire with a 0.25 mm diameter is used as a cutting tool to machine a stainless-steel work piece metal. Work piece dimensions were (51 x 25x 10) mm as shown in Figure (3). Pure (distilled) water was used as a dielectric fluid and was cut to 16 bits (25x 15x10) mm dimensions. The sample was placed on the machine's working table under various conditions as shown in figure (4). The chemical work piece composition is shown in table (1). The levels of cutting parameters in the table (2).

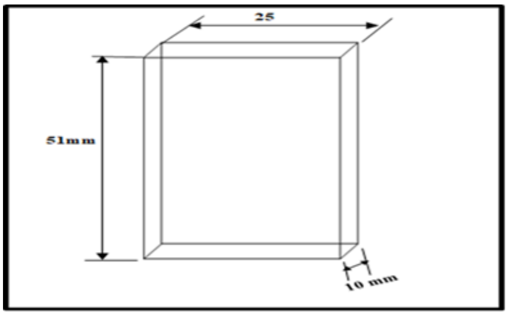

Figure 3: Sketching with dimensions for Work piece

Figure 4: The sample was placed on a machine WEDM work

Table 1: Composition chemical of stainless steel 310 L (measured)

Metals	Si%	C%	MN%	P%	S%	Cr%	Mo%	Ni%	Al%	Cu%	Fe%
Result	0.214	0.0229	1.54	0.0171	0.0005	25.73	0.0036	20.05	0.0073	0.0123	Bal.

Table 2: The cutting parameter's value in this study

No. Sample	Parameters	symbol	Level 1	Level 2	Level 3	Level 4	Units
1	Wire feed	**WF**	4	5	6	7	m/min
2	Wire tension	W_T	5	6	7	8	Kg_f
3	Servo voltage	**SV**	20	30	40	50	volt
4	Pulse on time	T_{ON}	15	20	25	30	µsec
5	Pulse off time	T_{OFF}	30	40	50	60	µsec

4. Results and discussion

4.1 Surface roughness results

Table 3 shows the experimental value and the predicted value. The analysis of factorial design was performed to suit models to test data generating residual parts when the response data are entered SR. The meaning of the results, including regular likelihood sections between the residuals versus the expected value when the distribution with ANOVA is normal. They show an obvious model, which implies that; each element in the regression model affects the SR. The points are fixed in a straight line and factorial expected value. Standard residual likelihood plots for SR are shown in Figure (5).

Table 3: Experimental values with and expected values for SR and MRR

No. sample	Wire feed m/min	Wire tension (kgf)	Servo voltage (V)	TON (μs)	Tuff (μs)	EXP. SR (μm)	Pred. SR (μm)	EXP. MRR (g/min)	Pred. MRR (g/min)
1	4	5	20	15	30	1.9333	1.930191	0.025072	0.025314
2	4	6	30	20	40	2.0866	2.041609	0.043874	0.040186
3	4	7	40	25	50	2.16	2.220651	0.035861	0.037407
4	4	8	50	30	60	2.1466	2.148141	0.017538	0.016976
5	5	5	30	25	60	2.0666	2.088193	0.033611	0.033357
6	5	6	20	30	50	2.49	2.515763	0.041712	0.044927
7	5	7	50	15	40	2.0433	1.978635	0.021245	0.025165
8	5	8	40	20	30	2.6666	2.668193	0.040515	0.036735
9	6	5	40	30	40	2.3866	2.350153	0.049523	0.045529
10	6	6	50	25	30	1.56	1.546136	0.032556	0.035025
11	6	7	20	20	60	2.12	2.126136	0.034571	0.037745
12	6	8	30	15	50	1.74	1.813025	0.027709	0.027242
13	7	5	50	20	50	2.19	2.161844	0.017348	0.018742
14	7	6	40	15	60	1.9	1.929604	0.015134	0.012476
15	7	7	30	30	30	2.4533	2.466733	0.052277	0.052793
16	7	8	20	25	40	2.2766	2.234494	0.032658	0.031584

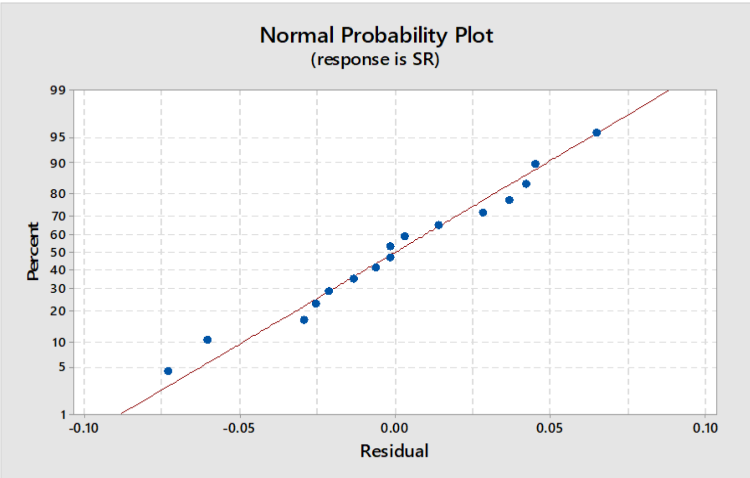

Figure 5: Normal probability plot for SR

Table 4 organizes the output of variance analysis (ANOVA) that includes the source of variation, DF, a total sum of squares (AdjSS), mean squares (AdjMS), F-values and P-values in order to determine if the variables contribute to the response significantly. The ANOVA shows that pulse on time (TON) has a maximum impact on the roughness of the surface. This coefficient shall be used to develop a statistical model; the quantitative relationship between input parameters and SR is obtained in the equation of regression (2).SR = 2.1708+0.2885 TON-0.2758 wire tension*Toff+0.2761 servo voltage*Toff+0.3853 wire feed*servo voltage*TON -1.2809 wire tension*servo voltage*Toff-1.1013 wire feed*wire tension*servo voltage*TON-0.2534 wire feed*wire tension*servo voltage*TON*Tuff (2)

A summary of the model shows statistics comparing how well the data fit into various models. The amount of variance of the observed answers determined by the R-Square (R-Sq) is shown in the model. It is also known as the coefficient of determination. The R-square is a modified R (R-Sq. (adj) and tailored to the number of terms of the template. The R square (R-Sq (pred) is a representation of the predicted future data. Higher R-Square (R-Sq.) and lower R-Square (R-Sq (adj)) values are more fitting for R-Square values. Table (5) for SR displays the details. Compare the SR values shown in Fig. (6) Experimented and anticipated. The proximity of both the experimented and projected SR curves showed approximately equal SR quantities.

Table 4: ANOVA table for SR

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	1.17353	0.167646	62.26	0.000
Linear	1	0.39556	0.395560	146.89	0.000
TON	1	0.39556	0.395560	146.89	0.000
2-Way Interactions	2	0.34597	0.172983	64.24	0.000
wire tension*Tuff	1	0.20773	0.207732	77.14	0.000
servo voltage*Tuff	1	0.09392	0.093922	34.88	0.000
3-Way Interactions	2	0.60022	0.300109	111.45	0.000
wire feed*servo voltage*TON	1	0.06248	0.062481	23.20	0.001
wire tension*servo voltage*Tuff	1	0.53774	0.537736	199.69	0.000
4-Way Interactions	1	0.35496	0.354960	131.82	0.000
Wire feed*wire tension*servo voltage*TON	1	0.35496	0.354960	131.82	0.000
5-Way Interactions	1	0.03768	0.037677	13.99	0.006
wire feed*wire tension*servo voltage*TON*Tuff	1	0.03768	0.037677	13.99	0.006
Error	8	0.02154	0.002693		
Total	15	1.19507			

Table 5: Description of the SR model

S	R-sq	R-sq(adj)
0.0518923	98.20%	96.62%

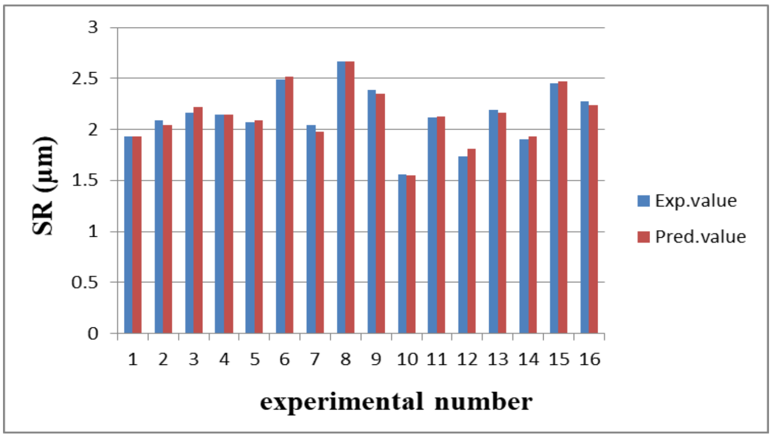

Figure 6: Relationship between measured and predicted for SR values

4.2 Metal removal rate results

The experimental value and the expected value are shown in Table (3). Factorial analysis of the models to be used to analyze data-producing residual parts when entering the MRR response data has been performed. The significance of effects like normal likelihood plots between residuals relative to their expected values when regression and ANOVA are the normal distribution. They display a simple pattern (i.e. points have been set in a straight line), meaning that every aspect of the regression pattern influences the MRR (the factorial expected value). The probability plots of normal residuals for MRR are shown in Figure (7).

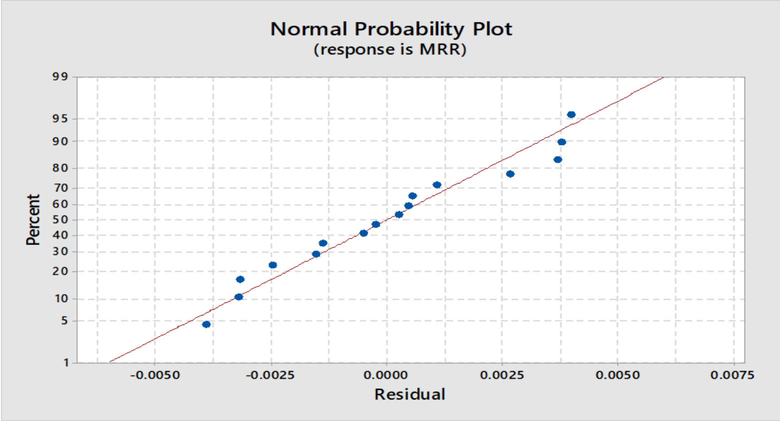

Figure 7: Normal residual probability plots for MRR

Table (6), which includes variation sources, degrees of freedom (DF), total square sums (Adj SS), medium squeezes (Adj MS), F-values and P-values, organizes the output of the various analyses (ANOVA) to determine whether the variables are significantly correlated with the response. The ANOVA shows that pulse on time (TON) has a maximum effect on metal removal rate.

Table 6: MRR has an ANOVA table

Source	DF	Adj SS	Adj MS	F- value	P- value
Model	9	0.001837	0.000204	12.34	0.003
Linear	4	0.000692	0.000173	10.46	0.007
Wire feed	1	0.000043	0.000043	2.62	0.157
Wire tension	1	0.000027	0.000027	1.62	0.250
Servo voltage	1	0.000087	0.000087	5.26	0.062
TON	1	0.000281	0.000281	17.00	0.006
2-way interactions	4	0.000498	0.000125	7.53	0.016
Wire feed*wire tension	1	0.000029	0.000029	1.75	0.234
Wire feed*servo voltage	1	0.000014	0.000014	0.87	0.387
Wire feed*TON	1	0.000299	0.000299	18.09	0.005
Wire tension*servo voltage	1	0.000057	0.000057	3.45	0.113
3-way interactions	1	0.000473	0.000473	28.63	0.002
WF*wire tension*servo voltage	1	0.000473	0.000473	28.63	0.002
Error	6	0.000099	0.000017		
Total	15	0.001936			

This coefficient is used to develop the statistical model; the quantitative relationship between input parameters and MRR is obtained in the equation of regression (3).

$$\begin{aligned} MRR = &-0.490 + 0.0807\ \text{wire feed} + 0.1071\ \text{wire tension} + 0.01526\ \text{servo voltage} - 0.00479\ \text{TON} - \\ &0.01743\ \text{wire feed*wire tension} - 0.002550\ \text{wire feed*servo voltage} + 0.001071\ \text{wire feed*TON} - \\ &0.002557\ \text{wire tension*servo voltage} + 0.000419\ \text{wire feed*wire tension*servo voltage} \end{aligned}$$

In a model summary, statistics demonstrate how well the data fit into various models. R Square (R-Sq), calculates the sum of the variance in the observed response, as shown by the model; the determination coefficient is also recognized. The R-Sq (adj) is a modified R adapted to the number of terms of the model. A measure of how well future data is expectable is the forecast R square (R-Sq (pred)). Higher R Square (R-Sq) and reduced R-Square (R-Sq (adj)) values mean better fit, as shown in the MRR Table (7). As shown in Figure (8), the comparison is observed and expected MRR values. The proximity of experienced and forecast MRR curves showed that the experiment.

Table 7: Description model for MRR

S	R Square	R-sq (adj)
0.0040641	94.88%	87.20%

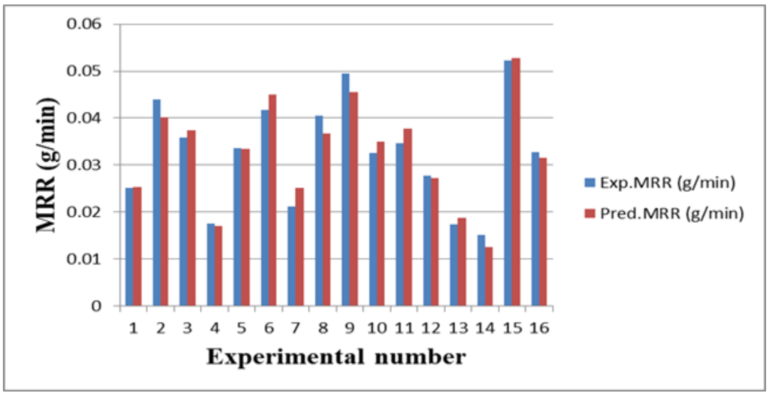

Figure 8: Comparison of experimented and predicted for MRR values

5. Conclusions

The present study addressed the process parameters WEDM (WF, WT, SV, TON and Tuff) on surface roughness and metal removal rate for stainless steel AISI 310 L metal used when the zinc-coated brass wire is used as a tool electrode. The factorial model is suggested to forecast MRR and surface roughness value. The outcome shows that the values tested and predicted are roughly identical. We can infer from the outcome that:

- The experiments show that metal removal rate and surface roughness are significantly influenced by the pulse on time.
- The best Surface roughness generated from zinc-coated brass wire (1.56µm).
- The maximum or best metal removal rate is (0.052277 g / min). When the values are somewhat medium range, they are the best and the wire does not break at this range. Wire feed (7m/min), wire tension (7 kgf), servo voltage (30 V), TON (30 µsec), Tuff (30 µsec).
- The independent value's ability to predict the rate of metal removal was tested (94.88 %).
- Using the factorial design approach to predict surface roughness, the coefficient determination (R-sq) is (98.20 percent).

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Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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