Investigating affecting parameters on surface roughness and metal removal rate in wire electrical discharge machining process

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Abstract: This article presents an approach to study the role of cutting factors on surface quality and material removal rate in (Wire Electrical Discharge Machining) process of O1 tool steel. Pulse duration, pulse pause time and working current were adopted as process parameters while surface roughness and metal removal rate were the outputs. Three levels of pulse on time have been used 10, 20 and 30 μsec while pulse off time was 10, 15 and 20 μsec and finally the current was 6, 8 and 10 A while the other parameters kept constant. The experiments showed that increasing pulse on time will increases metal removal rate and surface roughness, in addition increasing pulse off time will reduce metal removal rate but improving surface finish. Finally increasing the current will increase metal removal rate and reduce surface roughness.

1. Introduction
One of the established non-traditional thermal cutting technique to cut the materials that electrically conductive is wire electrical discharge machining process. The material removing mechanism is similar as the EDM technique. The electric sparks is the cutting tools, which have been controlled and introduced with the help of a generator [1]. In this process the wire (tool) is not touch the workpiece, the electric power transform to a voltage that produced threw the gap between tool (wire) and work material, and cuts a tiny bit of the work material. The electrolyte role is cooling the cutting region and washes debris between wire tool and workpiece to restrict them from cutting the next spark. The applications of this process are applied in the aerospace, tool industries and dies [2]. As WEDM has the ability to produce a fine, precision, corrosion and surfaces that resistant to wear, it has been considered in the present work. O1 tool steel has been adopted as the work material in the present research work because of its good properties which is found to satysfied present world needs.

Kanlayasiri K & Boonmung S. [1] [2] revealed that pulse duration and working current had been influential inputs influencing the surface quality during (WEDM) of DC53 die steel. The quality of surface of work material was decreased when the pulse duration and pulse peak current was elivated. Mao Yong Lin et al. [3] adopted micro-milling EDM for cutting of Inconel 718 and optimized the process inputs for finding required results of multiple response factors by using Grey Taguchi method. Sharma N et al. [4] proved that the pulse duration is an influential factor, which influenced cutting velocity and part dimensions in wire electrical discharge machining of HSLA steel. Experimental work had been conducted on the central composite design of response surface methodology. Neeraj Sharma et al. [5] revealed the role of inputs on material removal rate for WEDM using HSLA as work-piece. They found that material removal and surface irregularity maximized with increase of pulse duration and current. Anish Kumar et
al. [6] focused on the Wire Electric Discharge Machining process. They show extreme study on the WEDM research involving the optimization of the process parameters listing the role of the various inputs influencing the machining response and productivity. G. Selvakumar et al. [7] focused on the selection of the most influential machining factors combination for (WEDM) of 5083 aluminium alloy. RSM is adopted to optimize the process factors for material removal and surface finish. Somashekar K.P. et al. [8] presented the formulation and optimization of many process factors for the evaluation of the optimal process settings on a micro-wire electrical discharge process.

2. Experimental Procedure

O1 tool steel has been adopted as a workpiece in this work which is one of the most difficult to cut material and has many applications in tools and dies; machines sections manufacturing industries. The workpiece of O1 tool steel is a square sheet which has been divided into 27 pieces of 2 mm thickness. The characteristics of each portion are 33 mm in length (l), 30mm width (w) in the square shape as illustrative in figure (1).

Figure 1. workpiece before cutting

| Material       | % C | % Mg | % P  | % S  | % Si | % Cr | % Ni | % N  | % Fe |
|----------------|-----|------|------|------|------|------|------|------|------|
| Used O1 tool steel | 0.08 | 2.00 | 0.045 | 0.03 | 0.75 | 18-20 | 8-10.5 | 0.10 | balance |

Table 1. The composition of the O1-Tool Steel.

| Grade       | Tensile strength (MPa) min | Hardness Brinell (HB)max | Density (Kg/m³) | Elastic Modulus (GPa) | Thermal conductivity (W/m.K) At 100 °C | At 500 °C | Electrical Resistivity (nΩm) |
|-------------|----------------------------|--------------------------|-----------------|----------------------|----------------------------------------|-----------|-----------------------------|
| O1 tool steel | 515                        | 201                      | 8000            | 193                  | 16.2                                   | 21.5      | 720                         |

Table 2. Mechanical properties of work piece material

3. Selection of parameters

There are many input variables to be included in the WEDM process for calculating the optimum process response. Based on the researches, it was revealed that the variables such as current, pulse on time and pulse off time have a direct effect on the process response. Before manipulating the main WEDM tests, many empirical experiments have been made in order to find the suitable range for the input variables. The range of other process parameters is illustrated in table 3.
Table 2. EDM controllable parameters.

| Code | Parameter              | Levels |
|------|------------------------|--------|
|      |                        | 1  | 2  | 3  |
| A    | Working Current (A)    | 6  | 8  | 10 |
| B    | pulse Duration (µs)    | 10 | 20 | 30 |
| C    | pulse pause time (µs)  | 10 | 15 | 20 |

4. Design of Experiments

The number of experiments needed greatly influenced by design of experimentation. For this reason experiments must be carefully distributed. In this work, many machining tests (a total of 27 experiments) depends on a full factorial with three-level design ($3^3$) were utilized to reveal surface quality and metal removal rate. The selected OA and the levels of cutting parameters are listed in table (4).

Table 4. Coded cutting factors and real values.

| Exp. NO | Coded values | Real values |
|---------|--------------|-------------|
|         | A  | B  | C  | current | pulse duration | pulse off time |
| 1       | 1  | 1  | 1  | 6       | 20             | 15             |
| 2       | 1  | 1  | 2  | 10      | 10             | 20             |
| 3       | 1  | 1  | 3  | 6       | 20             | 10             |
| 4       | 1  | 2  | 2  | 6       | 30             | 10             |
| 5       | 1  | 2  | 3  | 8       | 30             | 20             |
| 6       | 1  | 2  | 1  | 8       | 20             | 10             |
| 7       | 1  | 3  | 3  | 10      | 20             | 20             |
| 8       | 1  | 3  | 1  | 8       | 10             | 20             |
| 9       | 1  | 3  | 2  | 6       | 10             | 15             |
| 10      | 2  | 1  | 2  | 6       | 20             | 20             |
| 11      | 2  | 1  | 3  | 8       | 20             | 20             |
| 12      | 2  | 1  | 1  | 10      | 10             | 10             |
| 13      | 2  | 2  | 3  | 10      | 30             | 20             |
| 14      | 2  | 2  | 1  | 10      | 20             | 15             |
| 15      | 2  | 2  | 2  | 8       | 10             | 15             |
| 16      | 2  | 3  | 1  | 6       | 10             | 10             |
| 17      | 2  | 3  | 2  | 6       | 10             | 20             |
| 18      | 2  | 3  | 3  | 10      | 30             | 10             |
| 19      | 3  | 1  | 3  | 8       | 30             | 10             |
| 20      | 3  | 1  | 1  | 8       | 30             | 15             |
| 21      | 3  | 1  | 2  | 10      | 20             | 10             |
| 22      | 3  | 2  | 1  | 10      | 10             | 15             |
| 23      | 3  | 2  | 2  | 6       | 30             | 20             |
| 24      | 3  | 2  | 3  | 6       | 30             | 15             |
| 25      | 3  | 3  | 2  | 8       | 20             | 15             |
| 26      | 3  | 3  | 3  | 10      | 30             | 15             |
| 27      | 3  | 3  | 1  | 8       | 10             | 10             |
5. Results

Table (5) explains the experimental readings of machining of O₁ tool steel depending on L₂⁷ (3³) mixed orthogonal array. The process outputs, Ra in µm and metal removal rate (mm³/min) has been measured and evaluated.

| Exp. NO | INPUTS          | OUTPUTS  |
|---------|-----------------|----------|
|         | current pulse on time pulse off time | MRR      |
| 1       | 6 20 15         | 3.46     |
| 2       | 10 10 10        | 2.84     |
| 3       | 6 20 10         | 4.19     |
| 4       | 6 30 10         | 4.93     |
| 5       | 8 30 20         | 3.47     |
| 6       | 8 20 10         | 4.93     |
| 7       | 10 20 20        | 3.56     |
| 8       | 8 10 20         | 3.28     |
| 9       | 6 10 15         | 3.39     |
| 10      | 6 20 20         | 3.88     |
| 11      | 8 20 20         | 3.96     |
| 12      | 10 10 10        | 4.63     |
| 13      | 10 30 20        | 4.38     |
| 14      | 10 20 15        | 4.31     |
| 15      | 8 10 15         | 3.78     |
| 16      | 6 10 10         | 3.53     |
| 17      | 6 10 20         | 3.56     |
| 18      | 10 30 10        | 5.27     |
| 19      | 8 30 10         | 4.68     |
| 20      | 8 30 15         | 4.33     |
| 21      | 10 20 10        | 4.45     |
| 22      | 10 10 15        | 4.18     |
| 23      | 6 30 20         | 4.62     |
| 24      | 6 30 15         | 4.64     |
| 25      | 8 20 15         | 4.89     |
| 26      | 10 30 15        | 4.84     |
| 27      | 8 10 10         | 3.43     |

5.1. Results for MRR

Figures (2) and (3) show the graph of effects Plot of machining factors vs the first response (metal removal rate) for mean and S/N ratio and table (6) which shows the results of means. As listed in this table, all the selected three factors of current (A), pulse duration (B) and pulse pause time (C) significantly affects both the mean and the variation in the (MRR) readings. It is found that the best parameters combination for maximum MRR is A₃ B₃ C₁, i.e., at current 10 A, pulse duration 30 µs and pulse pause time of 10 µs. It is suggested that the parametric combination within the considered range as mentioned above gives maximum metal removal rate. Using these data the optimum MRR can be predicted using the optimum cutting conditions mentioned above and according to the relation:

Predicted Mean (MRR) = A₃ + B₃ + C₁ - 2(average mean)

Where
A₃ = Average of (MRR) at the third level of current
B₃ = Average of (MRR) at the third level of pulse duration
C₁ = Average of (MRR) at the first level of pulse pause time
From Table (5.2):
Predicted Mean (MRR) = 4.273 + 4.573 + 4.449 - 2*4.126 = 5.043 mm³/min

Figure 2. Effects Plot for means of MRR.

Figure 3. Main effects Plot for signal to noise ratios of MRR.
Table 6. Response Table for Means of MRR

| Level | Current | Ton  | Toff |
|-------|---------|------|------|
| 1     | 4.022   | 3.624| 4.449|
| 2     | 4.083   | 4.181| 4.202|
| 3     | 4.273   | 4.573| 3.728|
| Delta | 0.251   | 0.949| 0.721|
| Rank  | 3       | 1    | 2    |

5.2. Results for Ra

Figures (4) and (5) show the graph of effects Plot of machining factors vs the second response (surface roughness) for mean and S/N ratio and table (7) which shows the results of means. As listed in this table, all the adopted machining factors of current (A), pulse duration (B) and pulse pause time (C) significantly influenced both the variation and the mean in the (Ra) values. It is clear that the optimal parameters combination for minimum Ra is A₁ B₁ C₃, i.e., at current 6 A, pulse duration 10 µs and pulse pause time of 20 µs. It is suggested that the parametric combination within the considered range as mentioned above gives minimum surface roughness. Using these data the optimum Ra can be predicted using the optimum cutting conditions mentioned above and according to the relation:

Predicted Mean (Ra) = A₁ + B₁ + C₃ - 2(average mean)

Where
- A₁ = Average of (Ra) at the first level of current
- B₁ = Average of (Ra) at the first level of pulse duration
- C₃ = Average of (Ra) at the third level of pulse pause time

From Table (5.2):
Predicted Mean (Ra) = 2.408 + 2.246 + 2.248 - 2*2.464 = 1.974 µm

![Main Effects Plot for Means]

Figure 4. Effects Plot for means of Ra


![Main Effects Plot for SN ratios](image)

**Figure 5.** Effects Plot for signal to noise ratios of Ra.

**Table 7.** Table for Means of Ra.

| Level | Current | Ton  | Toff |
|-------|---------|------|------|
| 1     | 2.408   | 2.246| 2.633|
| 2     | 2.520   | 2.409| 2.512|
| 3     | 2.466   | 2.739| 2.248|
| Delta | 0.112   | 0.493| 0.386|
| Rank  | 3       | 1    | 2    |

6. Conclusions

1- The experimental advantage of this work is the use of obtained optimal variables to enhanced the material removal rate and reduces surface irregularity of O1 tool steel.

2- Metal removal rate or MRR at optimal inputs (i.e. A₃B₃C₁) is maximized with maximizing current and pulse duration with minimizing pulse pause time.

3- It was revealed that the surface roughness is directly proportional to discharge current, pulse duration and inversely to the pulse pause time.

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