Optimization Multi Response on Electrical Discharge Machining Sinking Process Using Taguchi-Grey-Fuzzy Methods

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ABSTRACT

Electronic Discharge Machining (EDM) sinking applied widely in advance material manufacturing, every process parameter will count on this company. Their performance evaluated by some parameters such as surface roughness and tool wear ratio. Then they will be a dependent variable on this research. Independent variables on this research are electrode polarization, gap voltage, duty factor and pulse current. Every variable has three levels, except electrode polarization has two levels. This research conducting using Taguchi matrix orthogonal L18 (21×33) methods. The aim of this experiment is to evaluate optimization parameter process on EDM sinking, using Taguchi-Grey-Fuzzy methods. Characteristics response optimal applied are ‘smaller better’ for surface response roughness and tool wear ratio. This research using DAC tool steel as work-piece. DAC is most widely used as die for aluminum and zinc die-casting. The aim of this research is finding contribution of variable in EDM sinking parameter. Result of this research show contribution from variable process to reduce variance total observed response simultaneously, in order are electrode polarization on 49,53%, gap voltage on 23,52%, duty factor on 5,45% and pulse current on 9,92%. From validated optimization in confirmation experiment, to conclude combination variable process optimal response value is electrode polarization on positive, gap voltage at 50V, duty factor at 0.5 and pulse current at 12A.

Keywords: EDM sinking, electrode wear ratio, sourface roughness, Taguchi-grey-fuzzy.

1. Introduction

EDM is a thernoelectric machining process use to process conductive and semi conductive materials [1]. Electrical discharge machining (EDM) sinking is one of non-conventional machining process [2]. EDM sinking can process high hardness, ductile, heat resistance materials effectively [3]. This process can meet work-piece with complex geometry and tight tolerance requirement, who can’t be achieve with other machining processes, such as the milling, drilling even shaping machine. EDM sinking is a metal cutting process by using erosion that occurs for several electric spark jumps. Electric spark jumps occur periodically in the gap between the cathode (work-piece) and the anode (tool) in dielectric, that’s make EDM sinking have capability to processing work-pieces with complex contours [4]. Despite many technological advantages in shaping complex surfaces of hard materials, EDM sinking has several potential threats to both the direct surrounding of the workplace as well as to environment [5].

DAC tool steel is hot working tool steel with good balance of strength, toughness and heat resistance. This material has good machinability, by applied quenching treatment this material become tougher and increasing surface hardness [6]. This treatment make life cycle of dies became longer and stable. Applications of DAC material is dies for aluminum and zinc die-casting with low to medium pressure casting [7]. Tool wear ratio and surface roughness are two variable that very common to evaluate performance from EDM sinking [8]. Electrode wear ratio is a percentage ratio between volume of wasted electrodes and the volume of wasted material during machining [9]. Surface roughness is a characteristic of quality of final product [10].

2. Literature Review

2.1. Electrode wear ratio

Electrode wear ratio (EWR) is volume of electrode material who erosion and wasted during machining process [3]. The calculation of EWR using equation 1 [11]. On this research we measuring weigh of electrode before and after machining, using digital pocket scale with maximum capacity 200 gr and accuracy 0,01 g. Every parameter using different electrode include replication, it to make sure no contamination from previous machining.
\[ \text{EWR} = \frac{\Delta W_T}{\rho_T \cdot t_m} \]  
Equation (1)

\[ \Delta W_T = \text{electrode weight changing during machining (grams)} \]

\[ \rho_T = \text{electrode density (gm/cm}^3\text{)} \]

\[ t_m = \text{machining time (second)} \]

2.2. Surface roughness

Surface roughness is surface anomaly due to conditions of machining process. In advance material manufacturing surface roughness have significant factor, due to friction, contact deformation, tightness of contact join, positional accuracy, tight tolerance heat and electric current conduction [12][13]. Based on that statement we can conclude surface roughness is critical factor on EDM sinking [14]. On this research, surface roughness data obtaining by measurement on surface workpiece using mitutoyo surftest 301. Direction of measurement conducting diagonally on the surface workpiece.

2.3. S/N ratio

Taguchi method is a design of experiment approach for optimization of process parameters [15]. On this research they are electrode polarization, gap voltage, duty factor and pulse current. First step on optimization applied Taguchi-grey-fuzzy method is counting S/N ratio for each response. Taguchi Method using S/N ratio approach to observe noise factor variables [16]. Response ratio of electrode wear and surface roughness has “smaller better” characteristics S / N ratio can be calculate with following equation.

\[ S / N = -10 \log \left[ \frac{1}{n} \sum_{i=1}^{n} y_i^2 \right] \]  
Equation (2)

\[ n = \text{number of replication} \]

\[ y_i = \text{characteristic values of observations.} \]

Based on S / N ratio quality characteristics, value of a large S / N ratio shows good performance characteristics.

2.4. Data normalization

S / N ratio normalization process is changing the value of the S / N ratio to a value between 0 and 1. S / N ratio normalization process is changing the value of the S / N ratio to a value between 0 and 1 [17]. It also conducted based on response quality characteristics. Quality characteristic of S / N ratio is ‘larger better’. Equation used in normalization process is as follows.

\[ x_i^* = \frac{x_i^k - \min x_i^k}{\max x_i^k - \min x_i^k} \]  
Equation (3)

Where, \( \forall k \) \( x_i^k \) is the largest value of \( x_i \) (k) for k-th, \( \min x_i^k \) response \( x_i \) (k) is the smallest value of \( x_i \) (k) for k-th response

2.5. Deviation Sequence

Apart from absolute value and result of largest value normalization, it means difference between 1 and normalized data. Deviation sequence determined by following equation.

\[ \Delta y_i(k) = [X_0(k) - X_i^*(k)] \]  
Equation (4)

2.6. Grey relational coefficient (GRC)

It shows correlation between ideal conditions (best) with actual conditions from normalized response. GRC will be declared 1 if normalized response matches with ideal conditions. Equation used to get that value.

\[ \xi_i(k) = \frac{\Delta_{\min} + \xi \Delta_{\max}}{\Delta_{0,i}(k) + \xi \Delta_{\max}} \]  
Equation (5)

\( \Delta_{\min} \) is the smallest value of \( \Delta_{0,i} \), \( \Delta_{\max} \) is the largest value of \( \Delta_{0,i} \), and \( \xi \) is differentiating coefficient (common value is 0.5).

2.7. Fuzzification

Mapping methods use find a relationship between input variables and output variables based on fuzzy rules called fuzzy logic. The stages in fuzzy logic include fuzzification, followed by the applied fuzzy rules and defuzzification. Fuzzification is changing input variables that is GRC value from each response into a fuzzy number using membership function. Membership function used in this research is a triangular curve membership function as shown in Figure 1.

Figure 1. Membership function for electrode wear ratio and surface roughness

The membership classified into three fuzzy subsets classes, called small (S), medium (M) and large (L). Output variable of fuzzy logic system in this study is gray fuzzy reasoning grade (GFRG). The membership function used is the triangular curve membership function as shown in Figure 2. The GFRG membership function classified into five fuzzy cluster, called very small (VS), small (S), middle (M), larger middle (LM), larger (L).
2.8. ANAVA

Analysis of variance (ANAVA) is used to determine process variables that have a significant influence on responses and show how contribution of process variables to variable responses.

In this research, ANAVA conducted on GFRG. That mean a response representative from whole response. Statistically, the value of $F_{cal}$ shows process variable decision has a major influence on the response. The value of $F_{cal}$ and response variable are proportional. It means a contribution of response variable dependent on the value from $F_{cal}$. The contribution percentage shows portion (relative strength) of each process variable to total response, variance observed. If percent contribution error is less than fifteen percent, then no process variables have an denied effect but if percent of error contributions over fifteen percent show there are process variables that have denied effects.

3. Methods

This research using ZNC EDM Aristech LS-550 machine to process material and DAC Steel applied quenching treatment as material. Material wide 25mm, height 15mm and depth 5 mm. We using graphite as electrode and the dimension are wide 15mm, height 15mm and depth 5 mm. Previous research discuss about effect on electrode polarity to fatigue life tool in EDM sinking using high manganese steel workpiece and graphite electrode, was conclude EDM sinking using graphite electrode result material’s surface roughness has an effect on increasing the fatigue life [18]. Another research using tool steel specimen using zinc coated electrode wire EDM. This research conclude results smaller wire can make better surface roughness [19].

On this research, we apply design experiment four independent variables will be varieties. They are electrode polarization, gap voltage, duty factor and pulse current. Design experiment using matrix orthogonal $L_{18}(2^{11}x3^3)$ shown in Table 1.

| Combination | Electrode polarization | Gap voltage | Duty factor | Pulse current |
|-------------|------------------------|-------------|-------------|---------------|
| 1           | Negative               | 30 V        | 0.3         | 6 A           |
| 2           | Negative               | 30 V        | 0.5         | 9 A           |
| 3           | Negative               | 30 V        | 0.7         | 12 A          |
| 4           | Negative               | 40 V        | 0.3         | 6 A           |
| 5           | Negative               | 40 V        | 0.5         | 9 A           |
| 6           | Negative               | 40 V        | 0.7         | 12 A          |
| 7           | Negative               | 50 V        | 0.3         | 9 A           |
| 8           | Negative               | 50 V        | 0.5         | 12 A          |
| 9           | Negative               | 50 V        | 0.7         | 6 A           |
| 10          | Positive               | 30 V        | 0.3         | 12 A          |
| 11          | Positive               | 30 V        | 0.5         | 6 A           |
| 12          | Positive               | 30 V        | 0.7         | 9 A           |
| 13          | Positive               | 40 V        | 0.3         | 9 A           |
| 14          | Positive               | 40 V        | 0.5         | 12 A          |
| 15          | Positive               | 40 V        | 0.7         | 6 A           |
| 16          | Positive               | 50 V        | 0.3         | 12 A          |
| 17          | Positive               | 50 V        | 0.5         | 6 A           |
| 18          | Positive               | 50 V        | 0.7         | 9 A           |

This research conducted flown as flowchart shown on Figure 3.

![Figure 2. Membership function for output variable GFRG](image)

**Figure 2.** Membership function for output variable GFRG

**Figure 3.** Research Flowchart
4. Result

Based on experiment result we have electrode wear ratio (EWR) and surface roughness value ordered by design experiment matrix orthogonal L18 shown on Table 2

Table 2. Experiment Data

| Combination | Electrode Wear Ratio (µg) | Surface Roughness (µm) |
|-------------|----------------------------|------------------------|
|             | R1   | R2   | R1   | R2   |          |          |
| 1           | 2.84 | 2.60 | 9.00 | 8.56 |
| 2           | 2.68 | 2.57 | 10.10| 10.34|
| 3           | 2.67 | 2.65 | 12.12| 12.36|
| 4           | 2.84 | 2.85 | 9.57 | 9.12 |
| 5           | 2.68 | 2.52 | 10.82| 10.64|
| 6           | 2.62 | 2.60 | 12.25| 12.33|
| 7           | 2.68 | 2.55 | 9.44 | 9.52 |
| 8           | 2.47 | 2.48 | 11.04| 11.04|
| 9           | 2.63 | 2.55 | 8.90 | 9.14 |
| 10          | 2.45 | 2.47 | 8.62 | 8.85 |
| 11          | 2.54 | 2.50 | 6.50 | 6.71 |
| 12          | 2.47 | 2.52 | 8.20 | 7.95 |
| 13          | 2.57 | 2.54 | 7.08 | 7.25 |
| 14          | 2.39 | 2.42 | 8.66 | 8.53 |
| 15          | 2.62 | 2.67 | 8.67 | 9.12 |
| 16          | 2.40 | 2.36 | 8.08 | 8.26 |
| 17          | 2.42 | 2.40 | 6.13 | 6.32 |
| 18          | 2.42 | 2.38 | 7.87 | 8.09 |

Table 3 shows results of data processing to get the GFRG value. After getting GFRG value, next step is getting ANAVA. Table 4 shown result of ANAVA.

Table 4. ANAVA GFRG

| Variable process | D  | F  | SS  | MS  | F   | p<sub>val</sub> | Contribution |
|------------------|----|----|-----|-----|-----|---------------|--------------|
| electrode polarity | 1  | 0.08882 | 0.08882 | 73.72 | 0.000 | 49.53% |
| gap voltage | 2  | 0.04401 | 0.02201 | 18.27 | 0.000 | 23.52% |
| duty factor | 2  | 0.01205 | 0.00600 | 5.000 | 0.031 | 5.45% |
| pulse current | 2  | 0.01996 | 0.00998 | 8.290 | 0.008 | 9.92% |
| error | 10 | 0.01205 | 0.00120 | 11.58% | |
| total | 17 | 0.17690 | 0.17690 | 100% | |

Table 4. show all process variables Fcal value larger than Ftable. It can be conclude that statistically the polarity process variable electrode, gap voltage, duty factor and pulse current has significant influence from response observed electrode wear ratios and surface roughness simultaneously.

Determination of level combination of both process variables make optimum response can be determine base on largest average GFRG value. Optimum level from process variables are electrode polarity at level 2 (positive), gap voltage at level 3 (50 V), duty factor at level 2 (0.5) and pulse current at level 3 (12 A). Table 5 shows the results of calculation from average GFRG.

Table 5. Design experiment matrix orthogonal L<sub>18</sub> (2<sup>4</sup> x 3<sup>3</sup>)

| Variable process | Level 1 | Level 2 | Level 3 | Difference |
|------------------|---------|---------|---------|------------|
| electrode polarity | 0.4865 | 0.6270 | - | 0.1405 |
| gap voltage | 0.5286 | 0.5170 | 0.6265 | 0.1094 |
| duty factor | 0.5420 | 0.5931 | 0.5351 | 0.0580 |
| pulse current | 0.5240 | 0.5490 | 0.6009 | 0.0805 |
| total average | 0.5567 | |

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Table 6 shows the comparison of the results of the EDM sinking machining process under the initial conditions and at the optimum conditions. Based on Table 6, GFRG value at initial condition is 0.7028 and GFRG value at optimum condition is 0.7994. That showed the value of GFRG has increased by 13.75%.

Table 6. Result of confirmation experiment

| Response                          | Initial Combination (A1B1C1D1) | Optimum Combination (A2B2C2D2) | Forecast (A1B1C1D1) | Confirmation (A2B2C2D2) |
|-----------------------------------|--------------------------------|--------------------------------|---------------------|-------------------------|
| Electrode wear ratio (EWR)        | 2.39                           | 1.71                           |                     |                         |
| Surface roughness (SR)            | 10.77                          | 6.75                           |                     |                         |
| S/N Ratio EWR                     | -7.586                         | -4.643                         |                     |                         |
| S/N Ratio SR                      | -20.644                        | -16.586                        |                     |                         |
| GRG                               | 0.7028                         | 0.7994                         | 0.0364              |                         |
| Increasing GRG                    | 13.79%                         |                                 |                     |                         |
| S/N Ratio EWR                     | 38.79%                         |                                 |                     |                         |
| Increasing GRG                    |                                |                                 |                     |                         |
| S/N Ratio SR                      | 19.66%                         |                                 |                     |                         |
| Increasing S/N ratio              |                                |                                 |                     |                         |

Smaller better characteristic from response electrode wear ratio and surface roughness completed. This showed by an increasing value of the S/N ratio from each response. Increasing of S/N ratio in electrode wear ratio was 38.79% and the response of surface roughness was 19.66%.

5. Conclusion

This paper has given an overview about process variable on EDM Sinking, from the experiment we can conclude process variables have contribution on total variance from electrode wear ratio and surface roughness simultaneously were electrode polarity of 49.53%, gap voltage of 23.52%, pulse current of 9.92% and duty factor of 5.45%. Optimum combination settings that can produce a minimum response are electrode polarity set positive, the gap voltage at 50 V, the duty factor at 0.5 and the pulse current at 12 A. This research no comparable with previous research. A research conducted on 316L Stainless steel and copper carbide electrode has conclude that variable has significant effect are pulse on time, servo voltage and servo speed [12] this research using metal electrode, beside we using non-metal metal electrode and research observe process variable on micro EDM that open voltage and capacitor have the most effect on surface roughness because these two parameters are the main influence factors of discharge energy [14], this research using micro EDM and we using different parameter process. Although due on limitation of ZNC EDM Aristech LS-550 parameter process comparing on previous research. Summing up from the result above this research might helpful operator with similar machine to optimization on EDM sinking process.

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