Determining The Effect of Machining Parameters on Material Removal Rate of AISI D2 Tool Steel in Electrochemical Machining Process Using The Taguchi Method

Galang Sandy Prayogo and Nuraini Lusi

Mechanical Engineering Department, State Polytechnic of Banyuwangi, Jalan Raya Jember Km. 13 KabatLabanasemBanyuwangi, Indonesia.

E-mail : galangsandy@poliwangi.ac.id

Abstract. Electrochemical machining is non-traditional machining which is commonly used to manufacture hard materials and to produce complicated shapes of irregular sizes in the product. In this paper, an experimental study is given for drilling AISI D2 tool steel. The focus of this study is to optimize machining parameters based on the Taguchi L9 orthogonal array approach to maximize material removal rate (MRR). Voltage, a concentration of the electrolyte, and gap width were selected as machining parameters of ECM (electrochemical machining) process. The signal to noise ratio (SN) and the analysis of variance (ANOVA) are statistical methods used to investigate the effects of machining parameters. As the results, the maximum MRR is 0.153 g/min obtained at voltage 48 V, electrolyte concentration at 150 g/l, and gap width at 1 mm. electrolyte concentration is the machining parameters that most influence the response.

1. Introduction

Electrochemical Machining (ECM) is a non-conventional machining process where the tool does not have to be harder than the workpiece. ECM is one of the non-conventional machining processes, whose working principle is based on Faraday's law. This machining process utilizes chemical reactions and is accelerated with electrical energy, it is due to the oxidation reaction and reduction during electrolysis. At ECM the reduction and oxidation reactions are indicated by the decay (electron loss) of the workpiece and the addition of mass (attachment of positive metal ions to the tool). In the machining process, the ECM tool (electrode) does not come into direct contact with the workpiece. An electrical current passes through an electrolyte solution between a cathode tool and an anode workpiece [1]. The advantages of ECM are compared to conventional machining processes (turning and milling), which can process very hard materials, relatively small tool wear, smooth surface finishes of workpieces, and can produce workpieces with high precision and complex geometry in the absence of crack. ECM has been applied in many industrial fabrications including manufacturing of automotive parts, forging of dies, moulds, turbine blades, gears, aerospace, biomedical equipment, construction, and tribology[2–6].

Demands for quality in a manufacturing industry, such as material removal rate (MRR), surface roughness, precision, and geometric precision, become an obstacle to the machining process. To get the desired quality, the combination of process parameters must be determined precisely. Determining the combination of parameters in the manufacture of products with several quality characteristics targets is quite difficult to do, because of the complexity that is owned and must rely on a large number of series
of experiments. In addition to the demands of product quality, demands for high strength materials are also of concern.

Taguchi designs present a method of efficient experiment to design the optimum product consistently and with a variety of conditions. This method uses two, three, four, five, and fractional factorial mixture. Based on Taguchi experimental design as "off-line quality control ", it is a method to ensure good performance in the design phase of a product or process. Deepanshu et al.[7] optimize the response of MRR, overcut and surface roughness (Ra) of material mild steel with a diameter of 50 mm by using a copper electrode and solution of salt water as electrolyte. The method used is the orthogonal array Taguchi L9. Then optimized with the best process for the variable setting of the MRR, surface roughness and overcut. Three of the selected parameters as variables of the process are voltage, tool feed rate and the concentration of the electrolyte. Among these three factors, the feed rate is the most influential process variable toward MRR, followed by voltage and last is the concentration of the electrolyte. For surface roughness, the most influential are the feed rate than the concentration of the electrolyte and voltage. Overcut for a response, feed rate gives the most major influence, then the second is the voltage and the third is the electrolyte concentration. Chakradhar et al.[8] have found out the optimization machining process parameters for electrochemical machining of EN-31 steel by using Taguchi combined with grey relational analysis (GRA). The selected process parameters are electrolyte concentration, feed rate and voltage. The optimal process parameters that have been identified to yield the best combination of process parameters are electrolyte concentration at 15 %, feed at 0.32 mm/min and voltage at 20 V. Based on result of this study, the target performance characteristics, i.e. material removal rate can be maximized and the overcut, cylindricity error and surface roughness can be minimized through Taguchi method. Soni et al. [9] conducted experiment for drilling of LM6 AL/B4C composites using Taguchi L27 Orthogonal array and the results shows electrolyte concentration and voltage are the most significant machining parameters for affecting the MRR and overcut, and surface roughness.

2. The ECM Process

The principle of machining process i.e. ECM material with an anodic dissolving way (anodic dissolution) of a positively charged workpiece by a liquid electrolyte that flows through the gap (gap) between the workpiece and the tool that is negatively charged (cathode) as Figure 1 ECM process scheme. The workpiece as the anode is connected to the source of the positively charged currents while the tool is connected to the cathode as a source of direct current that is negatively charged and the electrolyte fluid flowed between the tool and the workpiece. Electrolytes used in the ECM needed for a chemical reaction on the surface of the workpiece. Electrolytes are given by means of sprayed or flushing between the electrode and the workpiece (the gap) so that the liquid electrolyte will serve as a medium to carry the heat reaction results from areas and to carry furious generated out of the gap so as to avoid snapping the particles snarled machining process on the results.

![Figure 1. The Electrochemical Machining process principal scheme](image-url)
3. Methods

3.1 Experimental Set Up

Experiments are conducted by using the prototype of electrochemical machining equipment. The ECM device consists of machining chamber, control panel, and electrolyte circulation system[11]. The work-piece position is fixed inside the machining chamber and the cathode (tool) is attached to the main screw which is driven by a stepper motor. Rectangular block of 20mm X 12 mm and 6mm height made of AISI D2 tool steel is chosen as the work piece for carrying out the experimentation to optimize the material removal rate. Sodium chloride (NaCl) electrolyte tends to produce matte finish with alloy steels[12]. NaCl is chosen as electrolyte to investigate the machining performance. In this study, MRR was measured based on weight loss during machining time:

\[
\text{Material removal rate (MRR)} = \frac{\text{Loss of weight}}{\text{Machining time}} \quad (g/\text{min})
\]  

3.2 Design of Experiment

An L9 orthogonal array has been chosen based on Taguchi quality design concept for conducted the experiment. The process parameters interaction effect has been assumed to be imperceptible [13]. The experiment were run randomly and rerun two times to attain accuracy and validity of test. Taguchi design method is to identify the machining parameter settings which render the quality of the product or process robust to unavoidable variations in external noise. The relative quality of a particular parameter design is evaluated using a generic signal to noise (S/N) ratio. Depending on the particular design problem, different S/N ratios are applicable, including larger is better and smaller is better. The S/N ratios for each type of characteristics can be calculated as follows[14]:

Larger is better (maximize):

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

and

Smaller is better (minimize):

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

4. Experimental Result and Discussion

Determination of design of experiments are crucial before the experiment began. In these experiments involves three parameters of machining processes, namely voltage, electrolyte concentrations and the gap width are varied. Each process parameters have three different levels as described in Table 1.

| Machining Parameters | Units | Level of Machining Parameters |
|----------------------|-------|------------------------------|
| Voltage              | Volt  | 24                           | 36 | 48 |
| Electrolyte concentractions | g/l | 100                           | 150 | 200 |
| Gap width            | mm    | 1                            | 2   | 3  |

This research aims to find out and determine the value of the best response from the response of the material removal rate (MRR), taking into account the number of factors involved, Taguchi experimental design method chosen to determine the sequence of experiments. Taguchi method offers a number of run fewer compared to the full factorial design, with the sequence run as is shown in Table 2.
Table 2. An L9 Orthogonal Array for Experimentation

| Run No. | Voltage (v) | Electrolyte Concentrations (g/l) | Gap width (mm) |
|---------|-------------|----------------------------------|----------------|
| 1       | 24          | 100                              | 1              |
| 2       | 24          | 150                              | 2              |
| 3       | 24          | 200                              | 3              |
| 4       | 36          | 100                              | 2              |
| 5       | 36          | 150                              | 3              |
| 6       | 36          | 200                              | 1              |
| 7       | 48          | 100                              | 3              |
| 8       | 48          | 150                              | 1              |
| 9       | 48          | 200                              | 2              |

Software of Taguchi methodology is used to analyze and to optimize the results. The S/N ratio of MRR (Larger the better) is calculated based on equation 2, that is used as a measurable value instead of standard deviation because as the mean decreases, the standard deviation also decreases and vice versa [15]. The results of measurements and S/N ratio of the response of MRR is shown in Table 3.

Table 3. Results for ECM Process

| Run No. | MRR (g/min) | S/N Ratio |
|---------|-------------|-----------|
| 1       | 0.067       | -23.478   |
| 2       | 0.080       | -21.938   |
| 3       | 0.060       | -24.437   |
| 4       | 0.052       | -25.679   |
| 5       | 0.070       | -23.098   |
| 6       | 0.053       | -25.514   |
| 7       | 0.069       | -23.223   |
| 8       | 0.153       | -16.306   |
| 9       | 0.070       | -23.098   |

The ratio S/N MRR response indicated by Table 4, to find out which level is best for each of the factors, along with the resulting trends, then the analysis continued to obtain a graphic value of S/N MRR. A plot is created based on the results of experiments to make it easier in the analysis, the graph depicts the increase or decrease in the response when the parameters are changed according to the level that has given a chance. Figure 2 shows the relationship of voltage, electrolyte concentrations, and machining gap with MRR response.

Table 4. Response Table for Signal to Noise Ratios

| Level | Voltage (v) | Electrolyte Concentrations (g/l) | Gap width (mm) |
|-------|-------------|----------------------------------|----------------|
| 1     | -23,28      | -24,13                           | -21,77         |
| 2     | -24,76      | -20,45                           | -23,57         |
| 3     | -20,88      | -24,35                           | -23,59         |
| Delta | 3,89        | 3,90                             | 1,82           |
| Ranking | 2 | 1 | 3 |
Figure 2 indicates that the highest obtainable MRR is 0.153g/minute found as A_3B_2C_1 when a voltage is set at level three of the 48 volts, electrolyte concentration is at a level two of 150 g/l, and the gap width is at level one, i.e. 1 mm. The higher the voltage then the MRR will be higher. This also applies to the electrolyte concentration, the higher the electrolyte will produce the higher value the MRR as well. For the gap width, the closer the distance between the tool and the workpiece, or in other words, the smaller the gap width, then the MRR will be higher.

Analysis of variance or commonly referred to as ANOVA used to find out which machining parameters significantly affect the response, in this case, is the MRR. ANOVA is a statistical method that can infer some important conclusions on the basis of analysis of the experimental data. The method is very useful for revealing the level of significance of influence of factor(s) or interaction of factors on a particular response [11]. Table 5 shown ANOVA of the response quality characteristic.

| Parameters of ECM | DF | SS   | MS   | F   | % Contribution |
|-------------------|----|------|------|-----|----------------|
| Voltage           | 2  | 0.0024 | 0.0012 | 2.98 | 21.33          |
| Electrolyte       | 2  | 0.003  | 0.0015 | 3.76 | 29.33          |
| Concentration     | 2  | 0.0011 | 0.0005 | 1.43 | 4.00           |
| Gap width         | 2  | 0.0008 | 0.0004 |     | 45.34          |
| Error             | 2  | 0.0075 |       | 45.34 | 100            |
| Total             | 8  | 0.0075 |       |     |                |

Fisher's F-test, in this case, is also used to determine the parameters of the machine which has a significant influence on the performance characteristics. F-value is defined as the ratio of the mean square for the term mean square error for the term. Based on ANOVA, Great F-value indicates that the variation of process parameters to make major changes to the performance characteristics. Degree of contribution of machining parameters also shown in Table 5. Based on the table, electrolyte concentration is the most significant factor for the MRR of ECM AISI D2. The composition of electrolyte play an important role in the improvement of MRR. Concentration is important factors influencing electrochemical dissolution[16]. The next sequentially process parameters are voltage and gap width.
5. Conclusion
The research presented the effects of machining parameters on the ECM process of AISI D2 tool steel. Based on the research that has been done is obtained that the concentration of the electrolyte and voltage has significant effects on response MRR while machining gap does not affect significantly to response MRR. The concentration of the electrolyte effects most to MRR at second rank is voltage and at third rank is gap width. The concentration of the electrolyte is the main contributor to the total variance of MRR. The setting of machining parameters that obtain the optimal MRR are voltage at level 3, electrolyte concentration at level 2 and gap width at level 1.

Acknowledgement
This research was supported by the mechanical engineering department and state polytechnics of Banyuwangi and funding research grant were provided by the Ministry of research, technology and higher education.

References
[1] H. Hocheng, Y. H. Sun, S. C. Lin, and P. S. Kao, “A material removal analysis of electrochemical machining using flat-end cathode,” J. Mater. Process. Technol., vol. 140, no. 1–3 SPEC., pp. 264–268, 2003.
[2] D. Deconinck, S. Van Damme, C. Albu, L. Hotoiu, and J. Deconinck, “Study of the effects of heat removal on the copying accuracy of the electrochemical machining process,” Electrochim. Acta, vol. 56, no. 16, pp. 5642–5649, 2011.
[3] R. Mathew and M. M. Sundaram, “Modeling and fabrication of micro tools by pulsed electrochemical machining,” J. Mater. Process. Technol., vol. 212, no. 7, pp. 1567–1572, 2012.
[4] K. P. Rajurkar, H. Hadidi, J. Pariti, and G. C. Reddy, “Review of Sustainability Issues in Non-Traditional Machining Processes,” Procedia Manuf., vol. 7, pp. 714–720, 2017.
[5] X. Chen, Z. Xu, D. Zhu, Z. Fang, and D. Zhu, “Experimental research on electrochemical machining of titanium alloy Ti60 for a blisk,” Chinese J. Aeronaut., vol. 29, no. 1, pp. 274–282, 2016.
[6] Z. Pandilov, “Application of Electro Chemical Machining for materials used in extreme conditions Related content Application of Electro Chemical Machining for materials used in extreme conditions,” 2018.
[7] D. Shrivastava, A. Sharma, and H. Pandey, “Experimental Investigation of Machining Parameter in Electrochemical Machining,” Int. Res. J. Eng. Technol., no. V, pp. 2395–56, 2015.
[8] D. Chakradhar and A. V. Gopal, “Multi-Objective Optimization of Electrochemical machining of EN31 steel by Grey Relational Analysis,” Int. J. Model. Optim., vol. 1, no. 2, pp. 113–117, 2011.
[9] S. K. Soni and B. Thomas, “A comparative study of electrochemical machining process parameters by using GA and Taguchi method,” IOP Conf. Ser. Mater. Sci. Eng., vol. 263, no. 6, pp. 8–15, 2017.
[10] D. Chaudhary and J. Nara, “Electrochemical Machining,” vol. 1, no. 7, pp. 620–624, 2014.
[11] M. K. Das, K. Kumar, T. K. Barman, and P. Sahoo, “Optimization of Surface Roughness and MRR in Electrochemical Machining of EN31 Tool Steel Using Grey-taguchi Approach,” Procedia Mater. Sci., vol. 6, no. Icmpc, pp. 729–740, 2014.
[12] S. Ayyappan and K. Sivakumar, “Investigation of electrochemical machining characteristics of 20MnCr5 alloy steel using potassium dichromate mixed aqueous NaCl electrolyte and optimization of process parameters,” Proc. Inst. Mech. Eng. Part B J. Eng. Manuf., vol. 229, no. 11, pp. 1984–1996, 2015.
[13] N. Lusi, K. Muzaka, and B. O. P. Soepangkat, “Parametric optimization of wire electrical discharge machining process on AISI H13 tool steel using weighted principal component analysis (WPCA) and taguchi method,” ARPN J. Eng. Appl. Sci., vol. 11, no. 2, 2016.
[14] B. O. P. Soepangkat, B. Pramujati, and N. Lusi, Optimization of multiple performance
characteristics in the wire EDM process of AISI D2 tool steel using Taguchi and fuzzy logic, vol. 789. 2013.

[15] I. Asiltürk and H. Akkuş, “Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method,” Meas. J. Int. Meas. Confed., vol. 44, no. 9, pp. 1697–1704, 2011.

[16] Z. Xu, X. Chen, Z. Zhou, P. Qin, and D. Zhu, “Electrochemical Machining of High-temperature Titanium Alloy Ti60,” Procedia CIRP, vol. 42, no. Isem Xviii, pp. 125–130, 2016.