Jurnal Polimesin
Department of Mechanical Engineering
State Polytechnic of Lhokseumawe
http://e-jurnal.pnl.ac.id/polimesin

e-ISSN	: 2549-1999	No.	: 1	Month	: February
p-ISSN	: 1693-5462	Volume	: 21	Year	: 2023

Received on 2022-09-06, Reviewed on 2022-10-2, Accepted on 2022-10-24, Copy edited on 2022-12-11, Layout edited 2023-01-30 and Available online on 2023-02-28

Optimization of S-EDM Process Parameters on Material Removal Rate Using Copper Electrodes

Khoirudin[1], Sukarman[1,*], Nana Rahdiana[2], Ade Suhara[2], Ahmad Fauzi[3]

[1]Department of Mechanical Engineering, University of Buana Perjuangan Karawang, Karawang, 41361, Indonesia
[2]Department of Industrial Engineering, University of Buana Perjuangan Karawang, Karawang, 41361, Indonesia
[3]Department of Informatics Engineering, University of Buana Perjuangan Karawang, Karawang, 41361, Indonesia
*Corresponding Author: sukarman@ubpkarawang.ac.id

Abstract

This article demonstrates that the Sinker Electrical Discharge Machining (S-EDM) method can be enhanced using SPHC (JIS G 3131) materials with a hardened surface. During S-EDM, neither contact nor a cutting force exists between the electrode and the work piece. S-EDM is advantageous because it eliminates mechanical stress, chatter, and vibration issues with traditional milling. S-EDM is widely employed, for example, in the manufacturing of molds for automotive and aviation components. Taguchi design and signal-to-noise ratio (S/N ratio) were selected to examine the impact of the input parameter model on the Material Removal Rate (MRR). The Taguchi approach assessed three input parameters and three experimental levels. The parameters of pulse current (I), spark time (T_{on}), and gap voltage (V_g) were chosen to evaluate the MRR performance of the S-EDM process with the SPHC-hardened work piece material. Copper with a diameter of 10 mm is chosen as the electrode material. This study aims to determine the optimal MRR for the chosen input variables. Results indicate that a more effective pulse current value promotes debris removal from the machining zone and stabilizes following spark release, speeding the Material Removal Rate (MRR). In the S-EDM machining process, the pulse current value significantly affects the MRR. It is one of the most significant response variables, followed by spark on time and gap voltage, with delta values of 4.64, 2.71 and 1.13, respectively. The Taguchi experiment has been successfully implemented and achieved the maximum MRR at 38.97, a pulse current of 16 A, a spark on time of 400 µs, and a gap voltage of 45 volts.

Keywords:
Electrical discharge machining, material removal rate, SPHC, signal-to-noise ratio, Taguchi design.

1 Introduction

Sinker Electrical Discharge Machining (S-EDM) is a non-conventional machining process using an electrode chisel to scrape the workpiece material and create dimensions and shapes [1]. The S-EDM process is widely applied to manufacture dies, moulds, and aeronautical and automotive parts [2]. S-EDM is a non-conventional machining process with an electrode chisel that functions to erode the material from the workpiece according to its shape. The S-EDM process is carried out with a system of two main components: the engine and the power supply. The machine controls the moving electrode tool to scrape the material and produce high-frequency sparks [3]. In S-EDM, there is no contact process and cutting force between the electrode (as a tool) and the workpiece material. The results are in the absence of chatter, mechanical stress, and vibration problems in conventional machining processes. The S-EDM process is widely used to manufacture moulds, dies, and automotive and aeronautical components [4]. Flushing the diffused particles from the inter-electrode gap is one of the most difficult challenges during S-EDM. Debris that builds up in the gaps between the electrodes can cause arcing and shorting. Surface finish and surface integrity are compromised as S-EDM results are generated [5].

Several studies with the theme of the S-EDM, among others, were carried out by [6], [7], [8] and [9]. Alaiakbari and Baseri conducted a S-EDM study through which optimal settings of the S-EDM process parameters have been determined. The process parameters are pulse current, pulse on time, and electrode rotation. With outcome variables in the form of MRR, surface roughness (Ra), Electrode Wear Rate (EWR), and overcut (OC), The Taguchi experimental design with three experimental levels was used to formulate the experimental layout using the X210Cr12 (SPK) workpiece material. The electrode material uses pure copper (99.9% Cu). The ANOVA method was used to determine the effect of significant parameters on the outcome. Current input parameters, pulse on time, electrode rotation speed, and electrode geometry are the most influential parameters on MRR, EWR and SR [6].

Further research was carried out by Sutan et al. by conducting a S-EDM study using the RSM method. The process parameters are pulse current, pulse on time, and peak current. The response variables were MRR, surface roughness (Ra), and Electrode Wear Rate (EWR). The Taguchi experimental design with three experimental levels was used to formulate the experimental layout using EN 353 steel workpiece material. The electrode material is pure copper. The results showed that the MRR, TWR and SR optimization values were 17.62 mm^3/min, 6.47 mm^3/min, and 4.54 mm^3/min, respectively, obtained at the optimum pulse time parameters pulse off time, and peak current of 100, respectively. Seventy-seven seconds, 25.43 seconds, and 45A, respectively [7]. Chandramouli investigated the S-EDM process using material precipitation hardened stainless steel (PH Steel) 17-4. The research was carried out through the optimal setting of the determined S-EDM process parameters. The selected process parameters are peak current, pulse on time, pulse off time, and tool lifetime, with outcome variables in the form of MRR and Ra. The Taguchi experimental design was used to formulate the experimental layout, and the experiment was carried out using PH Steel 17-4 material. The electrode material uses copper tungsten. The ANOVA method is used to analyze the effect of the input process parameters on the output response [8]. Advanced research was carried out by Wiercz et al. by conducting a S-EDM study using the Taguchi experiment. The selected process parameters are discharge current, pulse current, and pulse on time. The response variables used were MRR and surface roughness (Ra). The Taguchi experimental design and Response Surface Methodology (RSM) with three S-EDM parameters and three experimental levels were used to optimize the heat-treated tool steel 1.271 (55 HRC). The electrode material uses copper. The S-EDM results for the roughness Ra range from 1-2 m with the maximum possible value, so the MRR process optimization is carried out based on the desirability technique [9].

In contrast to previous studies, this study uses a Taguchi experimental approach using 3-parameter input and 3-level experiments. The input parameters are pulsed current, spark on time, and gap voltage. The voltage across the gap between the two electrodes is called "gap voltage." The chosen Material Removal

Rate (MRR) is used as the response variable in this study. This study aimed to obtain the optimum parameters for the MRR response variable. The research proposal will use the C-TEK ZNC-50A S-EDM machine.

2 Material and Method

2.1 Testing Materials and Specimens

SPHC steel sheet material work piece has been selected in this study. Material specifications, including chemical composition and mechanical properties, follow the JIS G 3131 standard [10] [11]. The material is prepared by stamping, hardening, and processed by the S-EDM machine. The copper material was selected for the S-EDM electrode process. The measuring instruments used in this research are digital weighing scales and calipers. Digital weighing scales are provided to evaluate the mass of work pieces and electrodes under conditions before and after machining, and digital calipers to measure the dimensions of work pieces and electrodes before and after the S-EDM process. The C-TEK ZNC-50A machine type S-EDM will complete this research proposal. The S-EDM process using the C-TEK ZNC-50A type occurs in Fig. 1. The work piece used in this research proposal uses SHPC (JIS G 3131) material with the material composition and mechanical properties referring to the standard [12]. The chemical composition is shown in Table 1.

Fig. 1. Process of S-EDM with copper electrodes.

2.2 Materials Removal Rates

Several variables, such as high Material Removal Rate (MRR) and surface roughness can be used to assess the performance of the S-EDM machining process. MRR has been selected for this S-EDM study's output variable. The rate of erosion of the work piece material, or MRR, is determined in the S-EDM process by generating an electric spark. MRR was performance calculated using experimental and theoretical approaches, which can be analyzed and calculated using eq. (1) [9] [13].

$$MRR = \frac{W_0 - W_1}{t.\rho} \tag{1}$$

MRR indicates the material removal rate transfer in mm^3/min; t represents the machining time in minutes and $\boldsymbol{\rho}$ is the work piece density (gram/cm^3) [14]. SPHC (JIS G 3131) material has a density of 7850 kg/m^3 or 0.008 g/cm^3. W_0 and W_1 indicate the work piece's mass before and after machining in grams.

2.3 S-EDM Parameter Selection

The S-EDM process refers to the controlled input parameters for each iteration, which are presented in Table 2. The S-EDM processing time (t) for each iteration is 2 minutes. The Taguchi technique is widely used in research and industrial implementation because it reduces variation in a manufacturing process with a robust experimental design. This condition allows collecting data needed to determine the input parameters significantly affecting product quality with a minimum number of experiments. Taguchi's experimental matrix is presented in Table 2.

2.4 Orthogonal Array (OA)

A matrix is typically used in Orthogonal Arrays (OA) to ensure a balanced level comparison within each factor. OA implements a matrix, typically used to determine the study material from a given group precisely. Each factor in this proposal will be evaluated at three levels. Taguchi's implementation, AO L9, has three control variables and three experimental levels, resulting in the eight degrees of freedom shown in Table 3 [16].

Table 1. Chemical composition of SPHC steel (JIS G 3131) [15] .

Spesifikasi material	C	Si	Mn	P	S	Ni	Cr	Cu	Ni+Cr
JIS G 3131	0.42-0.48	0.15-0.35	0.60-0.90	≤ 0.03	≤ 0.055	≤ 0.20	≤ 0.20	≤ 0.30	≤ 0.35
CPW0017*	0.410	0.002	0.194	0.0085	0.0032	0.000	0.000	0.000	0.000

*Certificate of analysis

Table 2. The S-EDM parameters and level experiment.

Code	Parameter	Symbol	Unit	Level		
				1	2	3
A	Pulse current	I	A (Ampere)	10	13	16
B	Spark on time	T_{on}	µs (micro second)	210	340	400
C	Gap voltage	V_g	V (Volt)	40	45	50

Table 3. The MRR data of the S-EDM process uses copper electrodes.

Run No.	Input parameters			Massa workpiece				MRR (mm^3/min)	
	Pulse current (A)	Spark on time	Gap voltage	m_o-R1	m_t_R1	m_o-R2	m_t_R2	R1	R2
1	10	210	40	20.69	20.06	20.30	19.66	16.11	16.38
2	10	340	45	20.30	19.37	20.39	19.48	23.76	23.13
3	10	400	50	20.39	19.28	20.27	19.16	28.26	28.35
4	13	210	45	20.27	19.17	20.55	19.47	27.90	27.63
5	13	340	50	20.55	19.20	20.27	18.93	34.29	34.02
6	13	400	40	20.36	18.88	20.55	19.09	37.71	37.17
7	16	210	50	20.25	18.84	20.36	18.96	35.82	35.73
8	16	340	40	20.58	19.06	20.58	19.08	38.70	38.34
9	16	400	45	20.33	18.80	20.33	18.81	38.97	38.79

2.5 Signal to Noise Ratio (S/N ratio)

The S/R ratio indicates how sensitive the input factor should be. Each chosen response variable does not always have the same characteristics. The Taguchi experiment generally yields three data attributes, as demonstrated by eq. (2), (3), and (4) [17][18].

Smaller is better:

$$S/N\ ratios\ = -10\ \log \sum_{i=1}^{n_0} \frac{y_i^2}{n_0} \qquad (2)$$

Larger is better:

$$S/N\ ratios\ = -10\ \log \frac{1}{n_0} \sum_{i=1}^{n_0} \frac{1}{y_i^2} \qquad (3)$$

Nominal is the best:

$$S/N\ ratios\ = -10\ \log \frac{\bar{y}^2}{s^2} \qquad (4)$$

where $\bar{y}$ is the data's average value and s is the standard deviation.

3 Results and Discussion

3.1 Material Removal Rate Analysis

MRR measures the work piece material's erosion rate per unit of time. It indicates the level of machining of the work piece. A high machining rate is always advantageous because it directly correlates with the output. The S-EDM process was carried out for 2 minutes, with the results presented in Fig. 2. A digital scale with an accuracy of 0.01 gram was used to calculate the MRR of the S-EDM process. The timing of the S-EDM machine was confirmed using a stopwatch, and eq. 1 was used to calculate the Material Removal Rate (MRR). The results of the MRR calculation of the S-EDM process are presented in Table 3 and the appearance of the S-EDM results using copper electrode material showed in Fig. 3.

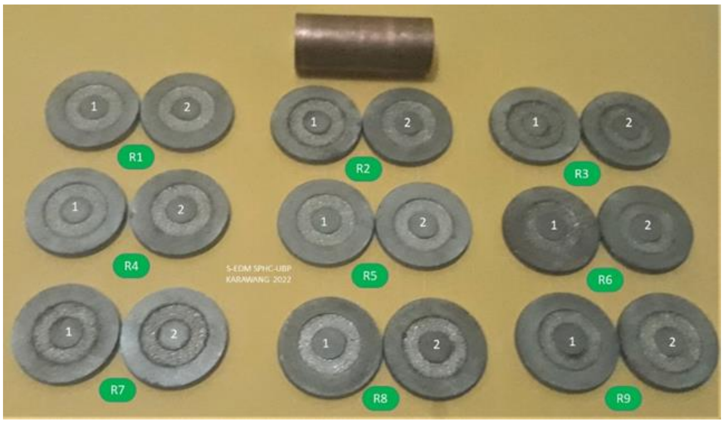

Fig. 2. The appearance of the S-EDM results using copper electrode material.

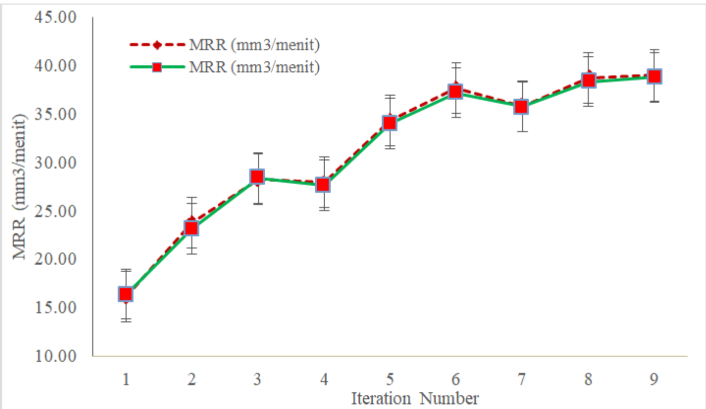

Fig. 3. The S-EDM process's Material Removal Rate (MRR) uses copper electrodes.

The MRR analysis considers the input parameter values of S-EDM, pulse current (I), spark on time (T_{on}), and gap voltage (V_g), when analyzing the work process. The MRR is reduced because the discharge energy sent to the machining zone is usually less when the pulse current has a minor effect. As a result, the machine cavity is reduced in depth, which allows debris to leave the machining zone more quickly. Conversely, a higher peak current corresponds to more incredible discharge energy, resulting in a deeper cavity. As the cavity depth increases, removing debris from the machining zone becomes more difficult. It causes a low MRR due to electrical discharge disturbances and short circuits. This condition is confirmed by the research conducted by [3][6].

The mass of the wasted work piece, namely the difference between the mass of the work piece before and after S-EDM machining, was used to generate experimental data for MRR. The lowest MRR is obtained in the first iteration, while the highest MRR is obtained in the 9th iteration. The effect of pulse current on the metal discharge rate indicates that as the pulse current increases, so does the metal discharge rate. The increased MRR and pulse current result from increased spark energy, facilitating melting and evaporation. This action increases MRR by advancing the impulsive force across the spark gap. These results follow previous study by [7] and the basic theory of S-EDM application [4]. Fig. 3 presents the MRR analysis of this investigation.

To generate sparks, a suitable "gap" must exist between an electrode and a work piece. This space is referred to as the "discharge gap." The range between the cloud and the surface of the work piece is very great, and the voltage reaches millions of volts. Higher voltage is directly proportional to MRR in S-EDM; however, it is incompatible with high-precision machining. Enhancement of the MRR by raising the discharge current, the gap voltage, and the pulse on time. This result is in line with previous study conducted by [19], which demonstrated that the MRR is directly proportional to the discharge current, the gap voltage, and the pulse on time.

3.2 S/N Ratio Analysis

The characteristics of the MRR data in the S-EDM process are “larger is better”. The characteristics of this data indicate that the output variable is directly proportional to the value of the S/N ratio [18] [20]. The S/N ratio is calculated using the 3rd equation [21] [22]. The results of the calculation of the S/N ratio of the S-EDM process are shown in Table 4. The S-EDM parameter with a large (delta) difference means that it significantly affects the response. In this study, pulse current I made the most significant difference according to its level concerning MRR. Fig. 4 showed the S/N ratio data mean for MRR in the S-EDM process.

Table 4. S/N Ratio MRR response table with data characteristics of the “larger is better”.

Level	Pulse current	Spark on time	Gap voltage
1	26.88	28.05	29.13
2	30.33	29.93	29.35
3	31.53	30.77	30.26
Delta	4.64	2.71	1.13
Rank	1	2	3

On the other hand, each level of the voltage gap parameter shows an almost negligible effect on the response. The phenomenon of S-EDM parameter analysis is presented in Fig. 4. These results confirm the research conducted by [6] and [8]. The characteristics of the MRR data in the S-EDM process are "larger is better". Based on the result, the optimum S-EDM operating parameters are obtained through the maximum level of each parameter. To get optimal MRR, S/N suggests setting parameters such as pulse current at level 3, spark on time at level 3, and gap voltage at level 3.

Fig. 4. The S/N ratio data mean for *MRR* in the S-EDM process.

4 Conclusions

The proper setting of the S-EDM non-conventional machining process parameters using copper electrodes was successful and the work piece material of low carbon steel (SPHC) to obtain the optimum MRR was successfully carried out with the following conclusions:

1. The three S-EDM machining parameters make a positive contribution to MRR.
2. An important parameter to get the highest MRR is 'pulse current' with a delta S/N ratio of 4.64, followed by spark on time and gap voltage. The delta S/N ratio spark values on time and gap voltage are 2.71 and 1.13, respectively.
3. Parameters in the 9th iteration reached the highest MRR with an average of 0.035 cm^3/min. This condition is achieved at the third experimental level of each selected parameter.

Acknowledgment

The authors gratefully to "The Ministry of Research, Technology and Higher Education" for funding this research through the "Penelitian Dosen Pemula" program for the fiscal year of 2022 with contract numbers 156/E5/PG.02.00.PT/2022; 077/SP2H/RT-MONO/LL4/2022; 05/LPPM/PDP/ VI/2022.

References

[1] E. C. Jameson, *Electrical Discharge Machining*. Dearborn: Society of Manufacturing Engineers, 2001.

[2] N. K. Singh and Y. Singh, “Experimental Investigation and Modeling of Surface Finish in Argon-Assisted Electrical Discharge Machining Using Dimensional Analysis,” *Arab. J. Sci. Eng.*, vol. 44, no. 6, pp. 5839–5850, 2019.

[3] P. Balasubramanian and T. Senthilvelan, “Optimization of Machining Parameters in EDM Process Using Cast and Sintered Copper Electrodes,” *Procedia Mater. Sci.*, vol. 6, no. Icmpc, pp. 1292–1302, 2014.

[4] H. El-Hofy, *Fundamentals of machining processes: conventional and non-conventional processes*. Boca: CRC Press, 2019.

[5] C. C. Wang and B. H. Yan, “Blind-hole drilling of Al2O3/6061Al composite using rotary electro-discharge machining,” in *Journal of Materials Processing Technology*, 2000, vol. 102, no. 1, pp. 90–102.

[6] E. Aliakbari and H. Baseri, “Optimization of machining parameters in rotary EDM process by using the Taguchi method,” *Int. J. Adv. Manuf. Technol.*, vol. 62, no. 9–12, pp. 1041–1053, 2012.

[7] T. Sultan, A. Kumar, and R. D. Gupta, “Material Removal Rate, Electrode Wear Rate, and Surface Roughness Evaluation in Die Sinking EDM with Hollow Tool through Response Surface Methodology,” *Int. J. Manuf. Eng.*, vol. 2014, pp. 1–16, 2014.

[8] S. Chandramouli and K. Eswaraiah, “Optimization of EDM Process parameters in Machining of 17-4 PH Steel using Taguchi Method,” *Mater. Today Proc.*, vol. 4, no. 2, pp. 2040–2047, 2017.

[9] R. Swiercz, D. Oniszczuk-Swiercz, L. Dabrowski, and J. Zawora, “Optimization of machining parameters of electrical discharge machining tool steel 1.2713,” *AIP Conf. Proc.*, vol. 2017, no. October, 2018.

[10] Japanese Industrial Standard, *JIS G 3131 Hot-rolled mild steel plates, sheet and strip Title*. 2010.

[11] A. Abdulah and S. Sukarman, “OPTIMASI SINGLE RESPONSE PROSES RESISTANCE SPOT WELDING,” *Multitek Indones. J. Ilm.*, vol. 6223, no. 2, pp. 69–79, 2020.

[12] Japanese Industrial Standard, *JIS G 4051 Carbon steels for machine structural use*. 2016.

[13] A. Moghanizadeh, “Reducing side overcut in EDM process by changing electrical field between tool and work piece,” *Int. J. Adv. Manuf. Technol.*, vol. 90, no. 1–4, pp. 1035–1042, 2017.

[14] Z. F. Emzain, U. S. Amrullah, A. Mufarrih, N. Qosim, and Y. D. Herlambang, “Design optimization of sleeve finger splint model using Finite Element Analysis,” *J. Polimesin*, vol. 19, no. 2, pp. 147–152, 2021.

[15] K. Khoirudin, S. Sukarman, S. Siswanto, N. Rahdiana, and A. Suhara, “Analysis of Spring-back and Spring-go on Variation of V-Dies Bending Angle Using Galvanized SGCC Steel Sheet,” *J. Tek. Mesin Mech. Xplore*, vol. 3, no. 1, pp. 17–25, 2022.

[16] P. J. Ross, *Taguchi Techniques for Quality Engineering*. New York: Tata McGraw-Hill, 2005.

[17] S. Sukarman, A. Abdulah, A. D. Shieddieque, N. Rahdiana, and K. Khoirudin, “OPTIMIZATION OF THE RESISTANCE SPOT WELDING PROCESS OF SECC-AF AND SGCC GALVANIZED STEEL SHEET USING THE TAGUCHI METHOD,” *SINERGI*, vol. 25, no. 3, pp. 319–328, 2021.

[18] S. Sukarman, A. D. Shieddieque, C. Anwar, N. Rahdiana, and A. I. Ramadhan, “Optimization of Powder Coating Process Parameters in Mild Steel (Spcc-Sd) To Improve Dry Film Thickness,” *J. Appl. Eng. Sci.*, vol. 19, no. 2, pp. 1–9, 2021.

[19] L. Selvarajan, M. Manohar, A. Udhaya kumar, and P. Dhinakaran, “Modelling and experimental investigation of process parameters in EDM of Si3N4-TiN composites using GRA-RSM,” *J. Mech. Sci. Technol.*, vol. 31, no. 1, pp. 111–122, 2017.

[20] K. Khoirudin, S. Sukarman, N. Rahdiana, and A. Fauzi, “ANALISIS FENOMENA SPRING-BACK / SPRING-GO FACTOR PADA LEMBARAN BAJA KARBON RENDAH MENGGUNAKAN PENDEKATAN EKSPERIMENTAL,” *J. Teknol.*, vol. 14, no. 1, 2022.

[21] S. F. Arnold, *Design of Experiments with MINITAB*, vol. 60, no. 2. 2006.

[22] A. Budianto, S. Sukarman, S. B. Jumawan, and A. Abdulah, “OPTIMASI RESPON TUNGGAL PADA PROSES TEXTURING BENANG DTY-150D / 96F MENGGUNAKAN METODE TAGUCHI SINGLE RESPONSE OPTIMIZATION OF DTY-150D / 96F YARN TEXTURING PROCESS USING TAGUCHI METHOD,” *Arena Tekst.*, vol. 35, no. 2, pp. 77–86, 2020.