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Influence of Process Factors on Electrode Wear Rate when EDM 90CrSi Steel using Graphite Electrodes

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Abstract: The findings of a study on the optimization of Electric Discharge Machining (EDM) procedure for processing cylindrically shaped components with graphite electrodes are presented in this paper. Tool steel 90CrSi was the material of choice for the study's workpiece. Additionally, the Electrode Wear Rate (EWR) was chosen as the optimization problem's objective function. An experiment using the Taguchi design was conducted to address this issue. Additionally, experiments were created and their outcomes were analyzed using the Minitab R19 program. The impact of the input process factors on EWR was investigated, including the powder concentration, the pulse on and off times, the servo current, and the servo voltage. Additionally, the best process variables for a minimal EWR were provided.

Key words: EDM, process factor, EWR, 90CrSi.

1. Introduction

The most popular non-traditional machining technique in the mechanical engineering sector is EDM (Electrical Discharge Machining). This technique is excellent for machining materials that are challenging to machine as well as recessed items like forgings and dies. However, this approach is constrained by its low rate of material removal and poor surface quality. These restrictions were removed by incorporating conductive powder into the dielectric solution, which changed the EDM technique into the PMEDM (Powder Mixture Electric Discharge Machining) process.

Numerous study findings on the EDM process have so far been published. How EDM process varia affected the output parameters was investigated. The influence of input parameters on SR (Surface Roughness) was presented in Refs. [1-4]. In Refs. [5-8], it was discovered how process variables affected the MRR (Material Removal Rate). The effect of input factors on the EWR (Electrode Wear Rate) was documented in Refs. [9, 10]. The effects of process variables on machining time when processing 90CrSi tool steel were discovered in Ref. [11]. Multi-objective optimization studies of the EDM process are also reported when machining SKD11 [12, 13] and 90CrSi [14, 15].

The findings of a study on EDM process optimization when treating 90CrSi tool steel with graphite electrodes are presented in this publication. The EWR was examined in relation to the EDM process parameters. Furthermore, ideal input process variables for the lowest EWR have been suggested.

2. Experimental Work

An experiment was conducted to assess the impact of input factors on EWR during the production of 90CrSi tool steel cylindrical pieces. The input parameters and their levels are shown in Table 1. Additionally, the experiment was designed and the data were analyzed using the Taguchi method in Minitab R19 software. Furthermore, for this experiment, the

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design L18 (6^1 + 3^4) was used. A Sodick A30 EDM, 90CrSi tool steel samples, graphite electrodes, 100 nm SiC powder, and Diel MS 7000 dielectric solution were utilized in the experimental setup, which is depicted in Fig. 1. The experimental design and EWR results are displayed in Table 2.

Table 1 Input factors and their levels.

No.	Input factors	Code	Unit	Level					
				1	2	3	4	5	6
1	Servo current	IP	A	3.5	3.5	7.5	9	11.5	13.5
2	Servo voltage	SV	V	4	5	6	-	-	-
3	Pulse on time	T_{on}	µs	8	12	16	-	-	-
4	Pulse off time	T_{off}	µs	8	12	16	-	-	-
5	Electrode type	TOG	-	HK0	HK15	HK20	-	-	-

Table 2 Experimental plan, EWR and S/N.

No.	IP	SV	T_{on}	T_{off}	TOG	EWR (mg/min)				
						Run 1	Run 2	Run 3	*S/N*	Mean
1	3.5	4	8	8	HK0	2.28	2.33	2.69	-7.75	2.43
2	3.5	5	12	12	HK15	0.73	0.78	0.93	1.72	0.82
3	3.5	6	16	16	HK20	0.61	0.38	0.75	4.42	0.58
4	5.5	4	8	12	HK15	1.64	1.86	1.49	-4.45	1.66
5	5.5	5	12	16	HK20	0.97	1.11	0.97	-0.17	1.02
6	5.5	6	16	8	HK0	3.26	3.38	2.95	-10.10	3.19
7	7.5	4	12	8	HK20	1.70	2.01	1.37	-4.69	1.70
8	7.5	5	16	12	HK0	5.54	5.19	5.91	-14.89	5.55
9	7.5	6	8	16	HK15	2.20	2.73	2.52	-7.93	2.48
10	9.5	4	16	16	HK15	0.92	1.05	0.70	0.89	0.89
11	9.5	5	8	8	HK20	0.60	0.89	0.93	1.74	0.80
12	9.5	6	12	12	HK0	2.47	2.21	2.65	-7.78	2.44
13	11.5	4	12	16	HK0	3.55	3.62	3.26	-10.83	3.47
14	11.5	5	16	8	HK15	1.63	1.75	1.46	-4.18	1.61
15	11.5	6	8	12	HK20	0.94	1.04	0.92	0.29	0.97
16	13.5	4	16	12	HK20	1.69	1.92	1.56	-4.75	1.72
17	13.5	5	8	16	HK0	4.64	4.78	4.38	-13.26	4.60
18	13.5	6	12	8	HK15	2.55	2.30	2.79	-8.14	2.55

(a) EDM machine (b) Samples and electrodes.

Fig. 1 Experimental setup.

3. Results and Analysis

The Minitab R19 software and the ANOVA (Analysis of Variance) method were utilized to assess the impact of the input process factors on EWR. Given that the EWR is as small as better, the subsequent prerequisite must be met:

$$S / N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (1)$$

Tables 3, 4, and Fig. 2 display the average EWR ($\overline{EWR}$) as determined by ANOVA. The results show that the electrode type TOG has the biggest impact on EWR (63.97%), followed by the servo voltage (1.95%), servo current (30.42%), pulse on time (0.64%), and pulse off time (0.23%).

It is evident from Table 4 and Fig. 2 that IP has a significant impact on EWR. When IP is 3.5 A, the EWR is lowest. The EWR drops, grows, and reaches the least value at level 2 (12 µs) as the pulse production time increases. The short T_{on} shortens the time it takes for the solvent to ionize. As a result, there is less of an impact from ions and electrons on the electrode surface, which lowers EWR and produces an unstable machining process. EWR rises when T_{on} is large because the spark's energy increases.

EWR increases with T_{off}, with level 1 (8 µs) having the lowest value. This could be because of the short T_{off}, which prevents the dielectric solution from fully recovering and results in unstable machining. The spark discharge at this point only lasts a very brief period of time, which causes the EWR to drop. The dielectric solution is more stable the larger the T_{off}. As a result, the amount of ions and electrons acting on the electrode surface increases, raising the EWR.

EWR rises with increasing Ip, with level 1 (4 A) having the lowest value. The spark's energy grows as Ip increases, which is why EWR will also increase.

Table 3 ANOVA's results for *S*/*N*.

Analysis of variance for means							
Source	DF	Seq SS	Adj SS	Adj MS	F	P	C (%)
IP	5	9.7503	9.7503	1.9501	8.72	0.028	30.42
SV	2	0.6246	0.6246	0.3123	1.40	0.347	1.95
T_{on}	2	0.2052	0.2052	0.1026	0.46	0.662	0.64
T_{off}	2	0.0746	0.0746	0.0373	0.17	0.852	0.23
TOG	2	20.5016	20.5016	10.2508	45.82	0.002	63.97
Residual error	4	0.8948	0.8948	0.2237			2.79
Total	17	32.0512					100.00
Model summary							

S	R-Sq	R-Sq(adj)
0.4730	97.21%	88.13%

Table 4 Effect order of process factors on *S*/*N*.

Response table for means					
Level	IP	SV	T_{on}	T_{off}	TOG
1	1.277	1.980	2.159	2.048	3.615
2	1.958	2.400	1.998	2.192	1.668
3	3.241	2.035	2.258	2.175	1.131
4	1.379				
5	2.018				
6	2.956				
Delta	1.964	0.420	0.259	0.145	2.484
Rank	2	3	4	5	1

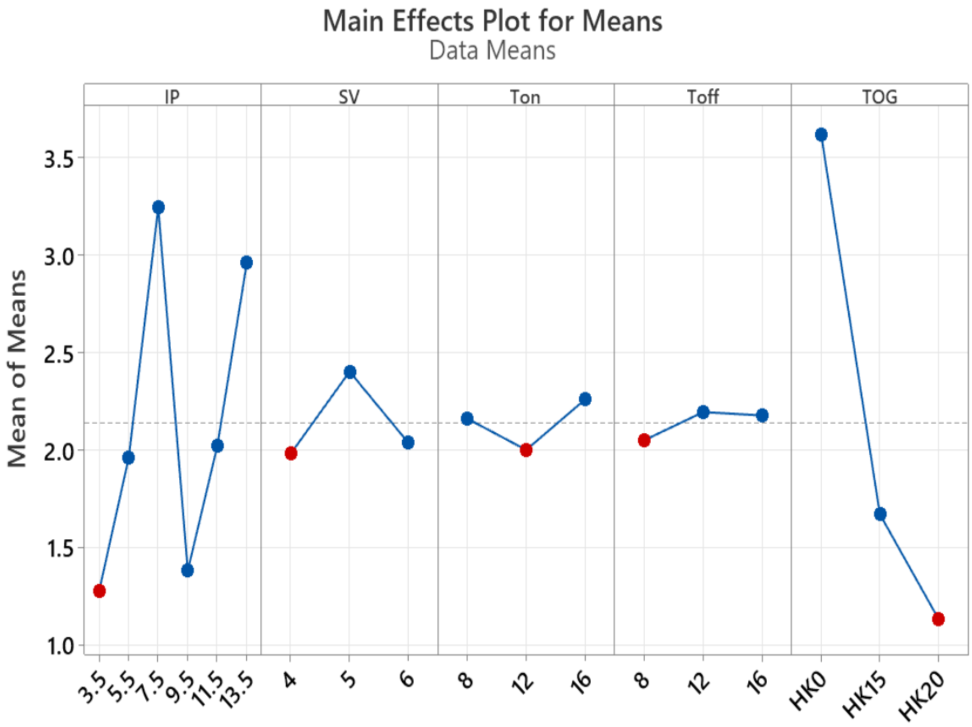

Fig. 2 Effect of process factors on $\overline{EWR}$.

EWR rises with increasing SV, then falls and reaches its minimum value at level 1 (4 V). The explanation is that when SV rises, so does spark energy, which raises EWR. But if SV is raised too high, the energy will be split up into ions and electrons, which will lower EWR.

Furthermore, it is evident that the electrode material significantly affects EWR. The electrode with the lowest EWR is HK20. The smaller and finer grain size of HK20 contributes to its decreased wear rate.

+) Determining optimum input factors:

As can be seen in Table 2, experiment number 3 yielded the lowest EWR, EWR = 0.58 mg/min (highest *S*/*N* ratio = 4.42) with the following input parameters: pulse electrode is HK20; T_{on} = 16 µs; T_{off} = 16 µs; IP = 3.5 A; SV = 6 V. This indicates that noise has the least effect and this experiment has the greatest impact on EWR. To get the least EWR, these parameters are not feasible. Consequently, in order to determine an appropriate amount of input parameters, it is important to assess the variation of the *S*/*N* ratio of EWR.

From Table 4 and Fig. 2, it can be seen that electrode HK20 (TOG3), T_{on} = 12 µs (T_{on}2), T_{off} = 8 µs (T_{off}1), IP = 3.5 A (IP1), SV = 4 V (SV1) are the values and levels of the input parameters which give the largest *S*/*N* ratio. This is a reasonable level and value of input parameters to achieve the smallest EWR.

+) Predicting EWR value:

Table 4 demonstrates that SV, T_{on} and T_{off} have little effect on EWR. Accordingly, the levels of the parameters that have a significant impact on the *S*/*N* of the wear rate determine the anticipated average wear rate ($\overline{EWR}_{OP}$) value using the following formula:

$$\overline{EWR}_{OP} = \overline{TOG}_3 + \overline{IP}_1 - \bar{T}_{EWR} \quad (2)$$

in which, $\overline{TOG}_3$ is the average EWR corresponding to TOG at level 3; $\overline{IP}_1$ is the average MRR corresponding to IP at level 3; $\bar{T}_{MRR}$ is the average MRR of the entire experiment. And we have:

$$\bar{T}_{EWR} = \frac{\sum_{i=1}^{18} MRR_I + \sum_{i=1}^{18} MRR_{II} + \sum_{i=1}^{18} MRR_{III}}{54} \quad (3)$$

$$= 2.14 \text{ mg/min}$$

Substituting the values of the input parameters into Eq. (2) we have:

$$\overline{EWR}_{OP} = 0.27 \text{ mg/min}$$

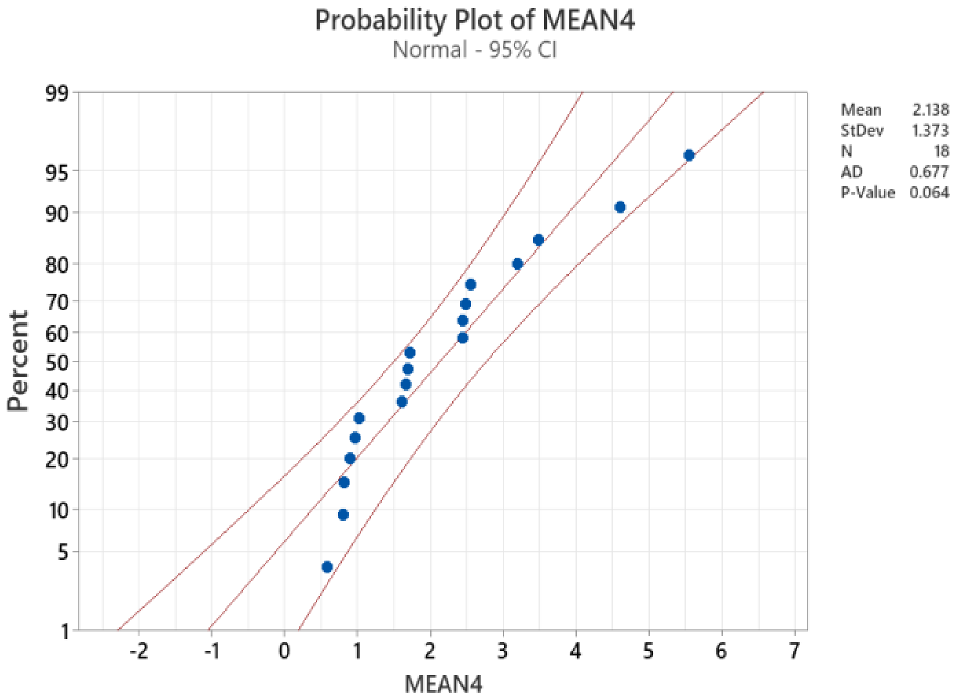

Fig. 3 Probability plot of MEAN.

An evaluation experiment was conducted with the input parameters: electrode HK20, T_{on} = 12 μs, T_{off} = 8 μs, IP = 3.5 A, SV = 4 V. The results were obtained average EWR after 3 experimental time is 0.478 mg/min.

Using Minitab R19 and the Anderson-Darling approach, the appropriateness of the experimental model with the suggested ideal process parameters was assessed. The experimental points, represented by the blue dots in Fig. 3, were found to be within the 95% significance level of the results. Furthermore, the *p*-value of 0.064 is higher than α = 0.05. This demonstrates that the applied empirical model is in line with the significance level mentioned above.

4. Conclusions

The optimization study conducted on EDM cylindrical shaped parts manufactured of 90CrSi tool steel in order to obtain the lowest EWR is presented in this paper. Graphite was the electrode material employed in this investigation. Additionally, five input parameters were selected for the study: the servo voltage, servo current, the pulse on time, the pulse off time, and the electrode type. These included counting the powder concentrate. An assessment was conducted on the impact of the input process parameters on the *S*/*N* ratio. Electrode type TOG was shown to have the most effect on EWR (63.97%), with servo voltage (1.95%), servo current (30.42%), pulse on time (0.64%), and pulse off time (0.23%) following closely behind. Furthermore, SV has a negligible effect on EWR (0.12%). Additionally, the best input values for obtaining the lowest EWR were suggested.

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