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Parametric Optimization of EDM on EN19 using Grey-Taguchi Analysis

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Abstract

Objectives: Electro discharge machining (EDM) has been widely and effectively utilized as one of the niche cost-effective technology for machining of extremely tough, brittle and unique metals and alloys. However, obtaining a larger material removal rate (MRR) as well as diminished tool wear rate (TWR) with improved surface finish and minimum amount of overcut is the major challenging issue in the research field of EDM. This paper puts light on the aforesaid aspects of EDM through optimization techniques using Taguchi and Grey Relational Analysis. **Methods/Statistical Analysis:** The work piece material selected is circular shaped EN19 alloy steel and the tool is rectangular shaped Copper. Taguchi parametric design with L_{27} orthogonal array is utilized to conduct 27 experiments. With an objective to optimize the machining performance variables such as material removal rate (MRR), tool wear rate (TWR), machined surface roughness (SR) as well as the overcut (OC), a number of operational parameters of the machining process such as Pulse on time (Ton), open circuit current (Ip) and pulse duty factor (Tau) are consciously chosen. A statistical technique, Analysis of variance (ANOVA), is pursued to determine the pertinent parameters swaying the responses. Finally, the contours of machining characteristics are drawn to get a clear visualization of the effect of the crucial input variables on the process performances. **Findings:** As an outcome of the research, pulse on time was observed to be a relatively more influential parameter swaying MRR and TWR followed by open circuit current and then pulse duty factor. Further, the work is extended by performing Grey Relational Analysis (GRA) to get a suitable combination of critical parameters in order to optimize the overall machining performance of EDM. The suitable combination of input parameters are I_p = 30 A, T_{on} = 3000 μs, Tau = 12 resulting maximum MRR, minimum TWR, minimum SR, and minimum OC. **Application/Improvements:** Very less paper are reported on optimization of all the crucial machining responses such as MRR, SR, TWR and OC simultaneously using a rectangular shaped tool. However, this paper results an appropriate combination of machining parameters in order to optimize all the aforesaid responses together taking the complexity of tool as well.

Keywords: ANOVA, EDM, GRA, MRR, OC, SR, TWR

1. Introduction

EN 19 is a high quality alloy steel with very good ductility, superior strength, improved wear and shock resistance properties. This superior strength alloy steel finds its applications mostly in high load studding, gears and shafts. Machining of EN 19 using conventional processes to achieve the desired degree of accuracy is very difficult. However, EDM, the nonconventional machining process involving spark erosion has been argued to be a better option for such alloys.

A large number of research papers have been reported exploring the EDM machinability of such difficult to cut alloys and materials. Some explicative observations are presented here. In[1] studied the behavior of EDM performance parameters such as surface roughness, electrode wear etc. towards electrical process parameters like pulse shape or discharge energy. Peak current and pulse duration are found to be the relevant parameters in terms of influencing the process performances. In[2] used support vector machine, a supervised learning method to develop a model for EDM. Therein also utilised particle swarm

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optimization technique to optimize SVM parameters for EDM process with high speed steel as work piece. EDM of Ti based alloy was studied by[3] using grey relational optimization. The results concluded that 40V, 200 µs pulse on time, 18 A current and 8% duty cycle yielded optimum EDM performance. In[4] explored the plausible influence of EDM parameters on surface finish using EN19 material and RSM tool. They argued that pulse on time and peak current as the critical players in surface finish. Similar efforts were made by[5] to link EDM process variables to the final surface quality using EN41 as the workpiece material and Grey-Taguchi analysis as the optimization tool. In[6] carried out an interesting work on change in dielectrics and its effect on EDM material removal rate. They also found that the pressure above the point of discharge is a critical parameter influencing material removal characteristics in EDM. In[7] explored the behavior of machining variables of a typical EDM process towards surface quality employing grey-fuzzy approach. The optimum combinations recommended were 10 µs pulse on time, 0.2s of tool work time and 1A current. In[8] applied teaching learning based optimization method to develop SVM model for EDM process. Another work in this direction by[9] concluded that 40 µs pulse on time, 150V and 14A peak current are the suitable combination of EDM variables to improve performance of AISI D6 machining. In[10] investigated the surface characteristics in the electro discharge machining of Ti-5Al-2.5Sn with graphite tool. It also suggested that positive polarity produces better surface quality than negative polarity.

From the above literature survey, it was established that optimizing the critical machining parameters to improve the machining performances in EDMing is vital which can effectively and efficiently produce better products. In this study, a die sinking EDM set up is used with EN 19 work piece and Cu tool to conduct a set of experiments and investigate the effects of crucial EDM parameters such as open circuit current etc. on MRR, TWR, SR and OC.

2. Experimental Details and Analytical Techniques

2.1 Experimental Set Up

The experiments are conducted in the die-sinking type EDM setup (ELECTRONICA SMART ZNC). Figure 1 shows the EDM set up used in this investigation and Figure 2 gives an idea on the spark production in the interelectrode gap between work and tool materials. Components of the standard EDM machine are the X-Y working table, reservoir and dielectric circulation system, pump, tool holder, servo control unitetc. EDM oil is used as the dielectric medium with side flushing. Pumps are used for circulation and filtration of the EDM oil for each run of the experiment. The amount of energy required for EDMing is consumed by the power supply control unit. Work holding device and tool holder are used for holding the work piece and tool during machining. Servo control unit is used for maintaining the predetermined gap.

Figure 1. EDM set up.

Figure 2. Production of spark with side flush.

2.2 Material Selection

The materials selected for the experiment are EN19 alloy steel as work piece with negative polarity, while the Copper as tool with positive polarity. The shape of the EN19 alloy steel is cylindrical shaped with the dimension of (50mm×50mm), while the shape of the Copper is rectangular shaped with the dimension of (70mm × 25mm × 12mm).

2.3 Design Strategy

The experiments are designed using Taguchi method and MINITAB16 software package. L_{27} orthogonal array is used to get more accurate results and dependency of the outputs on the individual parameters and all possible parameter combinations. The independent input parameters and their levels are shown in Table 1.

Table 1. Input parameters and levels

Machining parameter	Level I	Level II	Level III
Pulse on time (µs)	1000	2000	3000
Open circuit current (A)	20	25	30
Pulse duty factor	8	10	12

2.4 Performance and Measures

The response variables considered in this study are MRR, TWR, SR and OC. MRR and TWR are calculated using Weighing machine.

Surface roughness is measured by the surface roughness tester (Taylor Hobson Subtronic (25)). Overcut is measured with a vernierCaliper. Table 2 indicates the experimental results of L_{27} matrix. Figure 3 shows the work materials after machining for all the 27 runs.

Table 2. L_{27} orthogonal array

T_{on}	T_{au}	I_p	MRR	TWR	SR	OC
1000	8	20	2.0443	2.4023	3.6578	0.6
1000	8	25	2.5647	3.3118	5.6574	0.65
1000	8	30	3.6798	4.0009	5.9876	0.54
1000	10	20	2.5673	3.0005	3.5632	0.41
1000	10	25	3.6754	2.0007	5.7865	0.49
1000	10	30	4.5643	4.0018	6.1235	0.45
1000	12	20	2.6749	2.0008	3.9876	0.4
1000	12	25	3.7658	2.2421	5.8765	0.55
1000	12	30	5.0112	2.0009	6.1132	0.4
2000	8	20	6.1742	0.0001	4.8765	0.5
2000	8	25	12.9870	0.0002	6.7658	0.6
2000	8	30	10.0649	1.4013	6.9876	0.5
2000	10	20	8.9763	0.1808	4.9899	0.35
2000	10	25	9.8605	0.0002	6.9546	0.45
2000	10	30	15.5844	1.0002	7.1245	0.3
2000	12	20	4.1823	0.0007	4.9999	0.45
2000	12	25	6.3006	0.0002	6.9757	0.46
2000	12	30	12.483	0.0001	7.6547	0.39
3000	8	20	6.3459	0.0001	4.1256	0.6
3000	8	25	10.4964	0.0008	6.5822	0.58
3000	8	30	9.0160	0.1288	6.7123	0.55
3000	10	20	9.1185	0.1149	4.7654	0.4
3000	10	25	6.7340	0.0008	6.8976	0.4
3000	10	30	15.3483	0.0005	6.9876	0.3
3000	12	20	4.3956	0.0003	4.9888	0.35
3000	12	25	5.0325	0.0003	6.7896	0.45
3000	12	30	12.2913	0.0010	7.1235	0.4

Figure 3. Work material after machining.

3. Results and Discussions

3.1 Taguchi Approach (Single Objective Optimization)

As an optimization tool, “Taguchi method” is explored for MRR with the criteria “larger the better” and for TWR, SR and OC with the criteria changed to “smaller the better. ANOVA is utilized to find out the significant process parameters. The plots of material removal rate, tool wear rate, and surface roughness and over cut are shown in the figures Figure 4 to Figure 7 in order. The increase in MRR with pulse on time may be attributed towards the increasing spark energy between the inter electrode gap. However, after a certain optimum value of Ton, MRR starts to reduce as the plasma formed in the gap hinders the energy transfer. Increase in open circuit current (Ip) produces strong spark causing higher temperature and melting of work-piece resulting in increased value of MRR. Duty cycle (Tau) has less significant effect on MRR. With the increase in Ip, more heat is produced in the inter electrode gap causing the tool to erode and wear. Reduction in TWR, initially slowly and then rapidly with increase in Ton is the result of more plasma in the IEG obstructing the sparking process. SR increases with increase in Ip because of high temperature and more erosion and evaporation of work material. The phenomenon of overcut is an inherent process in EDM and cannot be avoided to achieve desired accuracy of after machining products. With increase in Ton and Ip, OC decreases initially, but then starts increasing due to high amount of plasma production and rapid melting and evaporation caused by very high temperature respectively.

Table 3. Symbols and their meanings

SYMBOLS	MEANING
$X_i^*(k)$	Normalized value for ith experiment using kth response
$X_i(k)$	Observed data for ith experiment using kthresponse
$Max\ X_i(k)$, $Min\ X_i(k)$	Maximum and minimum value of $x_i(k)$ for kthresponse
ζ	Grey relational coefficient
$\Delta_i(k)$	kth value in Δ_i different data series
ΔMax, ΔMin	Global maximum and global minimum value in different data series
ψ	Distinguishing coefficient lying between 0 to 1
γ	Grey relational grade
n	Number of responses

Table 4. Grey relational analysis results

Run	Normalized				Co-efficient				GRG	Rank
	MRR	TWR	SR	OC	MRR	TWR	SR	OC		
1	0	0.399711077	0.976879	0.142857	0.333333	0.454426	0.955802	0.368421	0.527996	20
2	0.038434	0.172432405	0.488158	0.000041	0.342099	0.376629	0.494148	0.333333	0.386552	27
3	0.120789	0.000234894	0.407454	0.314286	0.362526	0.333386	0.457647	0.421687	0.393811	26
4	0.038626	0.2502224	1	0.685714	0.342144	0.400071	1	0.614035	0.589063	15
5	0.120464	0.50006747	0.456605	0.457143	0.362441	0.500034	0.479205	0.479452	0.455283	23
6	0.186114	0	0.374239	0.571429	0.38055	0.333333	0.444144	0.538462	0.424122	25
7	0.046573	0.500042481	0.896273	0.714286	0.344014	0.500021	0.828189	0.636364	0.577147	18
8	0.127141	0.439731504	0.434608	0.285714	0.364203	0.471579	0.469311	0.411765	0.429214	24
9	0.21912	0.500009996	0.376757	0.714286	0.390356	0.500005	0.44514	0.636364	0.492966	22
10	0.305013	0.999971567	0.679017	0.428571	0.418414	0.999943	0.609026	0.466667	0.623513	10
11	0.80817	0.999966557	0.217255	0.142857	0.722721	0.999933	0.389789	0.368421	0.620216	11
12	0.592359	0.64983875	0.163045	0.428571	0.550879	0.588124	0.373984	0.466667	0.494913	21
13	0.511961	0.954833138	0.651301	0.857143	0.506053	0.91715	0.589137	0.777778	0.69753	3
14	0.577263	0.999965614	0.171111	0.571429	0.541866	0.999931	0.376254	0.538462	0.614128	12
15	1	0.750059973	0.129586	1	1	0.66672	0.364853	1	0.757893	2
16	0.157901	1	0.648857	0.571429	0.372551	1	0.587446	0.538462	0.624615	9
17	0.314348	0.999962018	0.165954	0.542857	0.421709	0.999924	0.3748	0.522388	0.579705	16
18	0.760999	0.999971567	0	0.742857	0.676589	0.999943	0.333333	0.660377	0.667561	6
19	0.317693	0.999985658	0.862544	0.142857	0.422902	0.999971	0.784368	0.368421	0.643916	7
20	0.624227	0.999997501	0.262129	0.2	0.570924	0.999995	0.403919	0.384615	0.589864	14

21	0.514893	0.967817148	0.230331	0.285714	0.507559	0.939527	0.393803	0.411765	0.563163	19
22	0.522463	0.971284877	0.706171	0.714286	0.51149	0.945689	0.629859	0.636364	0.68085	5
23	0.346356	0.999997001	0.185042	0.714286	0.433409	0.999994	0.38024	0.636364	0.612502	13
24	0.982563	0.999890154	0.163045	1	0.966301	0.99978	0.373984	1	0.835016	1
25	0.173655	0.999931294	0.65157	0.857143	0.376976	0.999863	0.589324	0.777778	0.685985	4
26	0.220693	0.999919196	0.211438	0.571429	0.390836	0.999838	0.38803	0.538462	0.579291	17
27	0.756789	0.999762817	0.12983	0.571429	0.672757	0.999526	0.364918	0.538462	0.643916	8

Table 5. Analysis of variance for grey relational grade

Source	DF	Seq SS	Adj SS	Adj MS	F	P
T_{on}	2	0.1593	0.1593	0.0796	32.96	0.000
T_{au}	2	0.0344	0.0344	0.01727.13	0.017	
I_p	2	0.0341	0.0341	0.01707.07	0.017	
T_{on}*T_{au} 4	0.0058	0.0058	0.0014	0.60	0.673	
T_{on}*I_p 4	0.0168	0.0168	0.0042	1.75	0.232	
T_{au}*I_p 4	0.0205	0.0205	0.0051	2.13	0.168	
Residual 8	0.0193	0.0193	0.0024			
Error						
Total	26	0.290569				

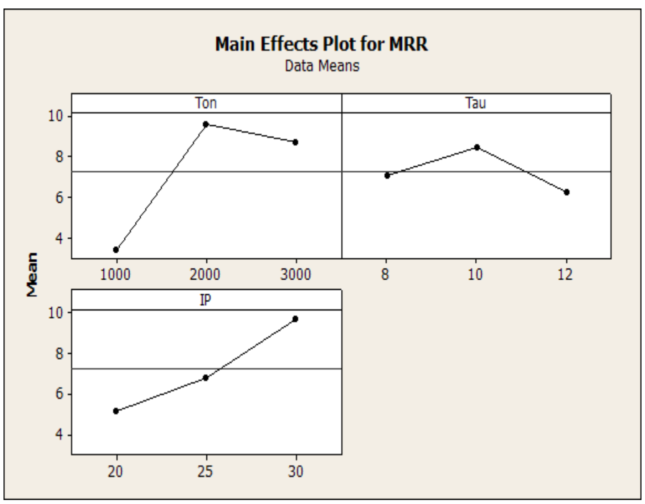

Figure 4. Main effects plot for MRR.

3.2 Grey Relational Analysis Approach (Multi Objective Optimization)

To find out the normalized value of MRR, "larger the better" criterion and for that of TWR, SR and OC, "smaller the better" criterion is used. The normalized values of responses using "larger the better" and "smaller the better" criteria can be expressed by (1) and (2) respectively. Grey Relational Co-efficient and Grey Relational Grade can be calculated by (3) and (4) respectively. Table 3 indicates the symbols used in the study.

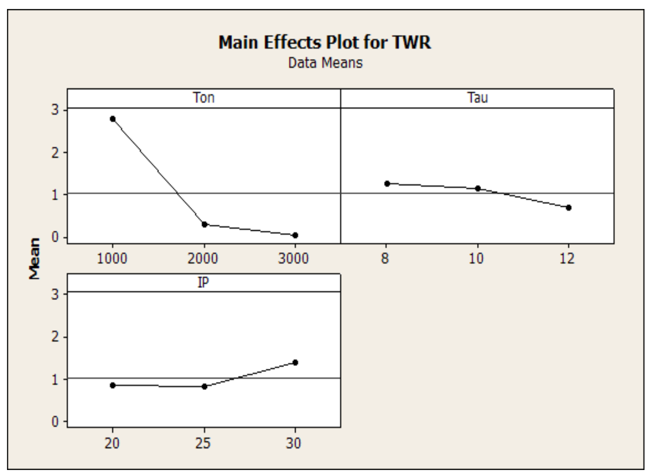

Figure 5. Main effects plot for TWR.

$$X_i^*(k) = \frac{X_i(k) - Min\, X_i(k)}{Max\, X_i(k) - Min\, X_i(k)} \quad (1)$$

$$X_i^*(k) = \frac{Max\, X_i(k) - X_i(k)}{Max\, X_i(k) - Min\, X_i(k)} \quad (2)$$

$$\zeta = \frac{\Delta Min + \Psi \Delta Max}{\Delta_i(k) + \Psi \Delta Max} \quad (3)$$

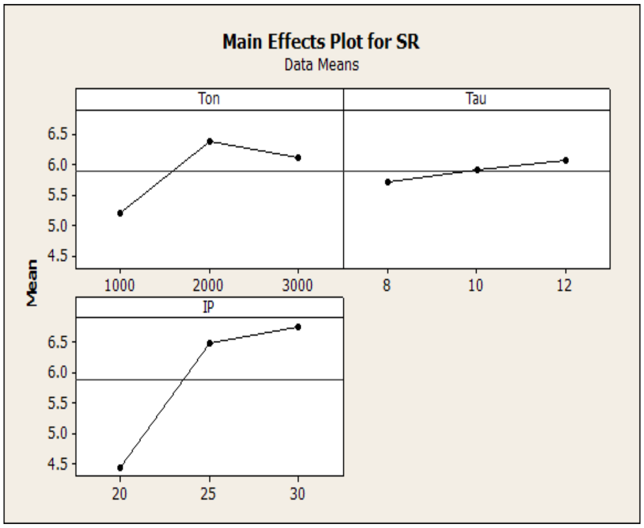

Figure 6. Main effects plot for SR.

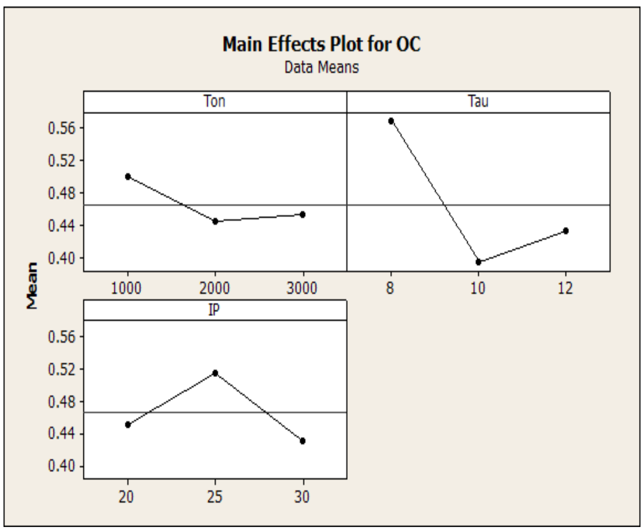

Figure 7. Main effects plot for OC.

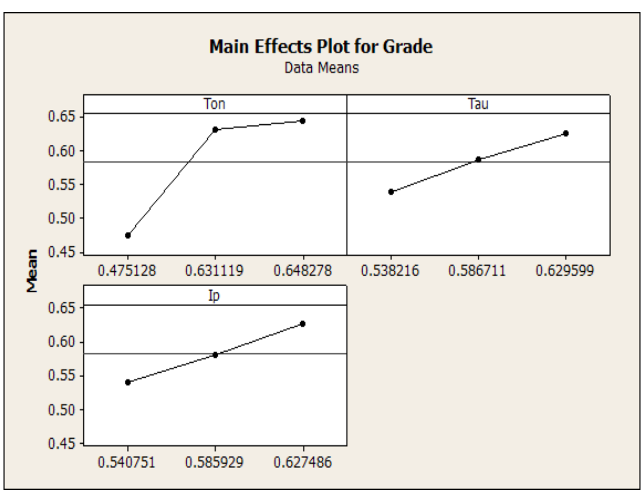

Figure 8. Main effects plot for GRG.

$$\gamma = \frac{1}{n}\sum_{i=1}^{n} \zeta_i(k) \tag{4}$$

Table 4 indicates the results of Grey relational analysis and the GRG of each run of the L27 matrix with a ranking. The ANOVA table for the GRG is shown in Table 5.

It is envisaged from the ANOVA of grey relational grade that, pulse on time has statistically significant effect on the EDM performance with 95% confidence interval. However, open circuit current and duty cycle also have major effect on EDM.

The main effect plot for GRG is shown by Figure 8. From the plot, it can be clearly observed that to produce optimum EDM performance measures, the suitable combination of input parameters are pulse on time (3000µs), open circuit current (30A) duty cycle (10%).

4. Conclusion

Experimental investigation and optimisation of die sinking EDM on EN 19 with Copper tool has been done and the following conclusions can be made.

Based on Taguchi optimisation method, it was found that all the machining parameters have significance to varying degrees on the performance measures. Initial increase in Pulse on time from 1000 to 2000 µs increases MRR and SR while reducing TWR and OC significantly. However, increase of open circuit current from 20 to 25 A increases all the performance parameters as MRR, TWR, SR and OC rapidly. Similarly, with an increase in duty factor from 8% to 10% increases MRR and SR while reducing TWR and OC.

Taguchi coupled Grey relational analysis is employed in the electro discharge machining to envisage the suitable combination of crucial machining parameters as pulse on time, open circuit current and duty factor to optimize the process responses as MRR, TWR, SR and OC. ANOVA for grey relational grade suggested pulse on time as the most significant parameter. Furthermore, main effect plot of GRG concluded the optimal parameter combination as Ton (3000µs), Ip (30A) and Tau (10%).

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