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Parameter Optimization of Wire-Cut EDM on Inconel Alloy for Maximizing Material Removal Rate †

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Abstract: In the existing investigation, the influence of wire-cut electrical discharge machining (WEDM) input factors such as pulse-on time, pulse-off time, wire tension, and taper angle on the material removal rate (MRR) on Inconel 825 was investigated. Experimental trials were performed according to the central composite design (CCD). An ANOVA test was conducted to evaluate the influence of the most significant WEDM process input parameter. The optimization of the response was achieved using the desirability approach to attain the maximum MRR. The optimum setting conditions were obtained as Ton of 0.8 µs, Toff of 38 µs, wire tension of 14 N, and taper angle of 2° for the MRR value of 2.98 g/min with a desirability of 1. Finally, the 3D surface plots were used to illustrate the variations of the output response with respect to input parameters.

Keywords: Inconel 825; central composite design; MRR; RSM; ANOVA

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1. Introduction

The wire EDM process is an advanced manufacturing process that does not employ sharp cutting tools used in standard machining processes, such as shaping, turning, and drilling. The traditional machining process is not feasible or economical due to reasons such as the tool being harder than the workpiece, difficulty in machining complicated shapes, and difficulty in achieving close tolerances. To overcome the above-mentioned difficulties, the CNC-assisted WEDM system was first introduced to the manufacturing industry, which brought about major progress in the manufacturing process. In the wire EDM process, the wire has to pass through the part to be machined. Vinod et al. [1] conducted the research work on an experimental investigation of the WEDM process on Monel 400. Four major influencing factors and two dependent variables were considered for the analysis. Maher et al. [2] optimized WEDM process parameters on AISI 1050 carbon steel. The researchers utilized neuro-fuzzy modeling to generate the empirical model and selected the machining parameters. Ravindranadh et al. [3] carried out the optimization of the WEDM process on ballistic-grade aluminum alloy components in armor applications. Goswami and Kumar [4] optimized the WEDM parameters on Niomic-80A material with the help of Taguchi's methodology. Lodhi et al. [5] optimized the WEDM process parameters on AISI D3 steel material using Taguchi's optimization approach. ANOVA was used to identify the influence of the selected parameter on the output response. The aim of this work is to investigate the influence of WEDM input parameters on the MRR for Inconel 825, employing CCD and ANOVA, and the desirability approach for optimization to achieve the maximum MRR.

2. Materials and Methods

Inconel 825 alloy contains iron, nickel, and chromium as the major constituents. It is highly corrosion-resistant and hinders machinability. The experiments were accomplished on the EXCETEK V650 WEDM machine. Copper wire of 0.25 mm diameter was employed as a tool electrode and deionized water as a dielectric fluid. The four input parameters, such as pulse-off time (Toff), pulse-on time (Ton), wire tension (WT), and taper angle (TA), were selected for optimization. The input parameters were considered at three levels, and the design of the experiments was framed using RSM (central composite design). The response parameter, such as MRR, was measured. Table 1 shows the input and response factors for WEDM machining.

Table 1. Design of Experiments.

Run	I:Ton (μs)	J:Toff (μs)	K:WT (N)	L:TA (Degree)	MRR in g/min
1	0.8	36	14	5	2.81
2	0.8	36	12	5	1.92
3	0.6	36	12	5	2.63
4	0.6	36	14	5	1.68
5	0.6	38	13	3	1.35
6	0.8	36	14	1	2.98
7	0.7	38	13	3	2.32
8	0.7	38	13	5	2.28
9	0.7	38	12	3	2.37
10	0.8	40	12	5	2.26
11	0.7	38	13	3	2.21
12	0.8	36	12	1	2.01
13	0.7	38	13	3	2.14
14	0.6	40	14	5	1.91
15	0.6	40	14	1	1.53
16	0.6	40	12	5	1.16
17	0.8	38	13	3	2.75
18	0.7	36	13	3	2.44
19	0.7	38	13	3	2.38
20	0.7	38	13	1	2.19
21	0.7	38	13	3	2.37
22	0.8	40	12	1	1.99
23	0.6	36	12	1	1.94
24	0.8	40	14	1	2.49
25	0.6	40	12	1	1.23
26	0.7	38	13	3	2.35
27	0.8	40	14	5	2.52
28	0.6	36	14	1	1.96
29	0.7	40	13	3	1.92
30	0.7	38	14	3	2.63

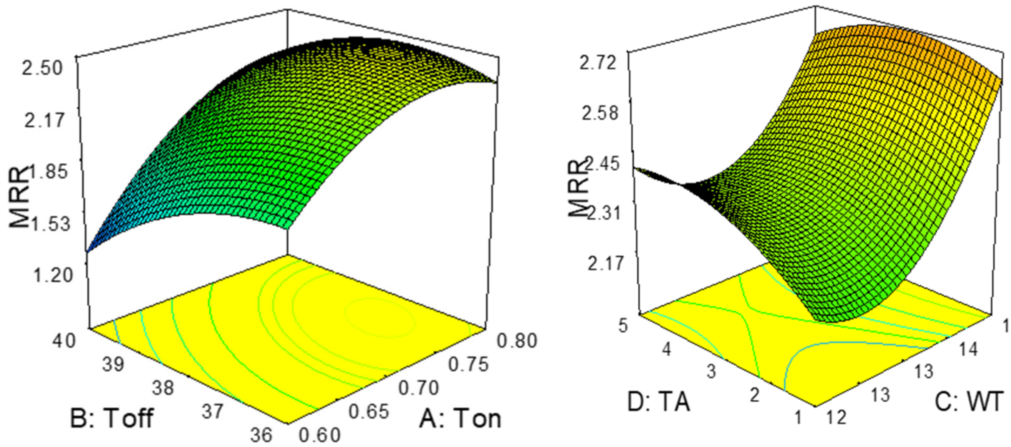
3. Results and Discussion

ANOVA was carried out to identify the major factor that affects the response parameters. It was conducted at 95% confidence intervals for the MRR and the results are displayed in Table 2. The model p-value less than 0.05 denotes that model terms are significant. In this case, for the MRR, the model terms I, J, K, and IK are significant. It is concluded that Ton, Toff, and WT are the important parameters that affect the response MRR.

Table 2. ANOVA results for MRR.

Basis	Sum of Squares	df	Mean Square	F Value	*p* Value Prob > F	
Model	4.720397	14	0.337171	4.310223	0.0040	significant
I-Ton	2.185742	1	2.185742	27.94139	<0.0001	significant
J-Toff	0.623848	1	0.623848	7.974956	0.0128	significant
K-WT	0.487599	1	0.487599	6.233209	0.0247	significant
L-TA	0.038999	1	0.038999	0.498544	0.4910	
IJ	0.263194	1	0.263194	3.364537	0.0865	
IK	0.390625	1	0.390625	4.993548	0.0411	significant
IL	0.037248	1	0.037248	0.476155	0.5007	
JK	0.046311	1	0.046311	0.592016	0.4536	
JL	0.014315	1	0.014315	0.183	0.6749	
KL	0.042628	1	0.042628	0.544928	0.4718	
I^2	0.161053	1	0.161053	2.058824	0.1718	
J^2	0.063829	1	0.063829	0.815956	0.3806	
K^2	0.104339	1	0.104339	1.333813	0.2662	
L^2	0.013326	1	0.013326	0.170358	0.6856	
Residual	1.173389	15	0.078226			
Lack of Fit	1.125639	10	0.112564			
Pure Error	0.04775	5	0.00955			
Cor Total	5.893787	29				

Figure 1a shows the 3D surface plot for the MRR of 12 mm thick Inconel 825 material machined by the WEDM process with varying values of Ton and Toff while keeping WT and TA constant. The MRR increases with increment in Ton due to extended machining and it decreases with increases in Toff. The MRR decreases when Toff increases due to the adverse heat loss that does not subsidize the MRR. Due to this, there will be a fall in the temperature of the specimen before the subsequent spark begins and the MRR, hence, decreases. MRR goes to the maximum value of 2.48 g/min at a high value of Ton (0.8 µs) and a minimum value of 1.48 g/min at a low value of Ton (0.6 µs). During maximum Ton and minimum Toff, the discharge takes place for a long time, which means a higher rate of discharge energy. Heavy sparks are absorbed between the workpiece and tool due to this higher rate of discharge energy and this heavy spark causes higher erosion of the workpiece and faster cutting speed is observed.



(**a**) (**b**)

Figure 1. Interaction plots showing the influence of (**a**) Ton and Toff on MRR; and (**b**) WT and TA on MRR.

Figure 1b shows the 3D surface plot for the MRR of 12 mm thick Inconel 825 material machined by the WEDM process with varying values of WT and TA while keeping Ton and Toff constant. While the MRR increases with an increment in wire tension, it does not vary in large amounts with respect to the taper angle. The best combination value for the MRR is 2.98 g/min, which could be obtained when machining with 0.8 µs pulse-on time, 38 µs pulse-off time, 14 N wire tension, and 2° taper angle.

4. Conclusions

The MRR increases with increment in Ton due to extended machining and decreases with increases in Toff. The MRR decreases when Toff increases due to the adverse heat loss that does not subsidize the MRR. Due to this, there will be a fall in the temperature of the specimen before the subsequent spark begins and the MRR, hence, decreases. The best-selected combination value for the MRR is 2.98 g/min, which could be obtained when machining with 0.8 µs pulse-on time, 38 µs pulse-off time, 14 N wire tension, and 2° taper angle.

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