

Modeling of EDM Progression on Heat Resistant Super Alloys Using Response Surface Regression

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Inconel 600 has been widely applied in aerospace industry and nuclear reactor due to its superior high temperature mechanical properties such as resistance to oxidation and corrosion, high tensile stress and rupture stress etc. But, machining of Inconel 600 is very difficult to machine material. Electric Discharge Machining (EDM) is one of the most extensively used non-conventional material removal process and current, pulse on time and pulse off time are the parameters that affects the quality of the machined component. Modeling of the EDM operation is essential for improving the quality of product while machining Inconel 600. Response surface methodology (RSM) incorporating statistics tool in design and executing experiments is proved. The Taguchi technique is very attractive and effective method to deal with responses influenced by number of variables. So, in this investigation, optimum parameters were obtained using Taguchi techniques and regression coefficient was obtained using response surface regression.

Keywords: Inconel 600, Electric Discharge Machining, Response surface methodology, Heat Resistant Super Alloys

Introduction

Heat Resistant Super Alloys (HRSA) maintains excellent mechanical strength at elevated temperatures, typically between 700° C and 1100° C. It represents among the largest group of materials in aerospace industries. HRSA exhibit exceptional properties such as corrosion resistance, creep resistance, and retaining strength and hardness at elevated temperatures. Among HRSA, nickel based alloys are most widely used nowadays for various manufacturing processes. Inconel 600 is one among the most commonly used alloys and also find its application in aero engine parts, rotor blades, casing rings and engine parts. Inconel 600 super alloy is very difficult to machine material¹. Hence, there is a need for a process which is capable of machining the materials economically and accurately. Electric Discharge Machining is one such machining process, which utilizes electric discharge to create heat energy by which the material is melted and removed from the work piece. This enables it to perform with high precision machining on any electrically conductive materials regardless of the material hardness. The

absence of contact between the tool and the work piece in the EDM eliminates mechanical stresses, chatters and vibration problems. The greater advantages of the EDM is the ability to machine complex shapes and the possession of greater adaptability in performing micromachining of holes to produce nozzles, orifices, slits and dies for micro components, for dimensions ranging from a few micrometers to hundreds of micrometers². Surface finish is a very important aspect for designing mechanical elements and also presented as a quality indicator of manufacturing processes. An optimum selection of process condition is extremely important as this one determines the surface quality and electrode wear phenomena of the manufactured parts. In EDM operations, an improper selection of cutting parameters will cause undesired surface roughness and high tooling cost. Minimization of wear is the predominant factor which improves the surface finish of the product³. Design of experiments is a powerful tool for modeling and analysis of process variables over some specific variable which is an unknown function of these process variables. Taguchi methods has been widely utilized in engineering analysis and consists of plan of experiments with the objective of acquiring data in a controlled way, in order to obtain

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information about the behavior of a given process⁴. Response surface methodology is a collection of mathematical and statistical techniques which are useful for modeling and analyzing engineering problems and developing, improving, and optimizing processes. It also has important applications in the design, development, and formulation of new products, as well as in the improvement of existing product designs, and it is an effective tool for constructing optimization models⁵.

Muttamara *et al*⁶ investigated the effect of electrode polarities in copper, graphite and copper infiltrated graphite electrodes in generation of conductive layer formation in EDM of alumina. Jahan *et al*⁷ experimented micro EDM of tungsten carbide using different electrode materials of tungsten, copper tungsten and silver tungsten and reported that the silver tungsten electrodes are capable of producing smooth and shiny surfaces with negligible amount of surface defects. Duarte and Arlindo investigated the influence of the hardness of the alloy steel on material removal rate and surface roughness of the work material⁸. Mahapatra and Amar patnaik⁹ have described in their paper about Parametric Optimization of Wire Electrical Discharge Machining Process using Taguchi Method. Lin *et al*¹⁰ have described, the grey relational analysis based on an orthogonal array and fuzzy-based Taguchi method is applied for optimizing the multi-response process. They have used both the grey relational analysis method without using the S/N ratio and fuzzy logic analysis in orthogonal array table in carrying out experiments for solving the multiple responses in the electrical discharge machining process. Most of the researchers have concentrated the turning, drilling and milling on Inconel but electrical discharge machining on Inconel 600 is not carried out. In this paper, in order to get optimum machining parameter and modeling the same for inconel600 in EDM, Taguchi technique and Response Surface Regression was used.

Materials and Methods

Experiments were performed using an electric discharge machine and the work piece material is Inconel 600 material. The different parameters such as current (5, 10, 15 amps), pulse on time (4, 5, 6 μ s) and pulse off time (5, 7, 9 μ s) were used for the experimentation. Kerosene was used as a dielectric fluid in this experiment. Taguchi's orthogonal array of L_{27} is used for this experiment. This needs 27 runs

and has 26 degrees of freedoms. It can conduct three levels of parameters. To check the degrees of freedom (DOF) in the experimental design, for the three levels test, the three main factors take 6 ($3 \times (3-1)$) DOFs. Square effects and interaction between parameters take the remaining DOFs.

Taguchi Techniques

The Taguchi method involves reducing the variation in a process through robust design of experiments. The overall objective of the method is to produce high quality product at low cost to the manufacturer. The Taguchi method was developed by Dr. Genichi Taguchi of Japan. He developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied; it allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. Analysis of variance on the collected data from the Taguchi design of experiments can be used to select new parameter values to optimize the performance characteristic^{11, 12}.

Response Surface Regression

Response surface regression is a collection of mathematical and statistical techniques for empirical model building. By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables). An experiment is a series of tests, called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response. Originally, RSM was developed to model experimental responses, and then migrated into the modeling of numerical experiments. The difference is in the type of error generated by the response. In RSM, the errors are assumed to be random^{13, 14, 15}.

Modeling of EDM Process Using Response Surface Regression

Fifteen observed responses are used to compute the model using the least square method. The two responses are associated with the three factors using the second-order polynomial. From the experimental data, quadratic regression models are obtained.

Table 1 shows the response surface regression of experiments with three independent variables for Inconel 600 in EDM. Usually it is necessary to check the fitted model in order to ensure that whether it provides an adequate approximation to the real system. Unless the model shows an adequate fit, proceeding with investigation and optimization of the fitted response surface is likely to give poor results. Graphical methods are the primary tool and the confirmations for graphical techniques are used to validate the models in this study. The normal probability plots are shown in Figure 1. The datas are plotted against a theoretical normal distribution in such a way that the points should form an approximate straight line, and a departure from this straight line would indicate a departure from a normal distribution, which is used to check the normality distribution of the residuals. It is reasonable that the assumptions of normality were satisfied in the data. The models are then checked using a numerical method employing the coefficient of determination ($R = R\text{-Sq}$). $R\text{-Sq}$ indicates how much of the observed variability in the data is accounted for by the model. The response surface models are developed in this study with values of $R\text{-Sq}$ say 92.6% and 95.6% for TW and SR respectively. Table 2 gives an insight into the linear, quadratic and interaction effects of the parameters for TW and SR. These analyses are done by Fisher's F -test and Student's t -test. This test is used to determine the significance of the regression coefficients of the parameters. The P value is used as a tool to check the significance of each factor and interaction between the factors. The larger magnitude of T and smaller the values of P are more significant

in corresponding coefficient term. The results in Table 2 indicate that pulse on is the most significant factor in determining the optimum TW with P value of 0.004 followed by interaction of current and pulse on with P value of 0.041. Coefficient of quadratic effect of current is found to be insignificant. Also Response surface regression for surface roughness is given in Table 2 and pulse on is the most significant factor in determining the optimum SR with P value of 0.050 followed by pulse off with P values of 0.173. Coefficient of interaction effect of current is found to be insignificant.

Optimization of EDM Process Using Taguchi Techniques

Taguchi method is applied for solving optimization problem with the objective of minimization of TWR and SR. The experimental results and S/N ratio for

Table 1—Response surface methodology for EDM

Trial	A	B	C	SR _{exp}	SR _{prd}	TWR _{exp}	TWR _{prd}
1	1	0	-1	2.367	3.35888	0.3277	0.366443
2	-1	0	-1	3.728	4.01813	0.0864	0.069183
3	0	0	0	5.089	5.08900	0.04013	0.040130
4	-1	0	1	4.761	3.76913	0.1204	0.081658
5	0	-1	1	4.237	5.13413	0.0293	0.092420
6	0	0	0	5.089	5.08900	0.04013	0.040130
7	0	0	0	5.089	5.08900	0.04013	0.040130
8	1	1	0	5.887	5.79225	0.4322	0.456577
9	0	1	1	5.286	5.67088	0.2366	0.195005
10	0	1	-1	6.712	5.81488	0.5618	0.498680
11	-1	1	0	5.019	5.62600	0.025	0.105337
12	-1	-1	0	3.224	3.31875	0.07316	0.048783
13	1	-1	0	5.142	4.53500	0.0642	0.016138
14	0	-1	-1	3.172	2.78712	0.0304	0.071995
15	1	0	1	6.101	5.81088	0.0535	0.070718

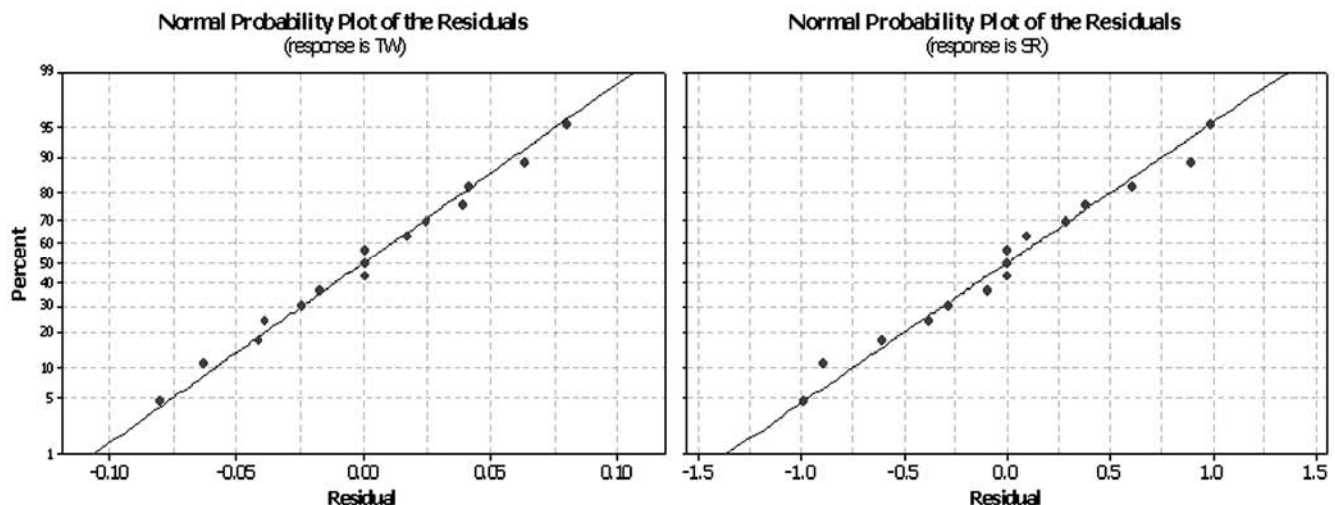


Fig. 1—Normal probability plots for TW and SR

Table 2—Response Surface Regression: TW & SR versus A, B, C

Surface Regression: TW				
Term	Coef	SE Coef	T	P
Constant	0.04013	0.04406	0.911	0.404
A	0.07158	0.02698	2.653	0.045
B	0.13232	0.02698	4.904	0.004
C	-0.07081	0.02698	-2.624	0.047
A*A	0.02049	0.03972	0.516	0.628
B*B	0.08802	0.03972	2.216	0.077
C*C	0.08638	0.03972	2.175	0.082
A*B	0.10404	0.03816	2.727	0.041
A*C	-0.07705	0.03816	-2.019	0.099
B*C	-0.08103	0.03816	-2.123	0.087
S = 0.07632 R-Sq = 92.6%				
Surface Regression: SR				
Constant	5.0890	0.5655	8.999	0.000
A	0.3456	0.3463	0.998	0.364
B	0.8911	0.3463	2.573	0.050
C	0.5508	0.3463	1.590	0.173
A*A	-0.4418	0.5097	0.867	0.426
B*B	0.1707	0.5097	0.335	0.751
C*C	-0.4080	0.5097	0.800	0.460
A*B	-0.2625	0.4897	0.536	0.615
A*C	0.6753	0.4897	1.379	0.226
B*C	-0.6228	0.4897	1.272	0.259
S = 0.9795 R-Sq = 95.6%				

TWR and SR are shown in Table 3. The Taguchi analysis for SR and TWR is given in Table 4; it clearly shows the optimal setting parameters for the minimization of TWR is current set as 5A, pulse on set as 4 μ s, pulse off set as 9 μ s; optimal setting parameters for the minimization of SR is at when current set as 5A, pulse on set as 5 μ s, pulse off set as 5 μ s.

Conclusion

The optimization of parameters and prediction of the responses in EDM on Inconel 600 using Taguchi and response surface regression were analyzed in this work. The following are the outcome of this work.

- Minimization of the surface roughness on Inconel 600 in EDM, current is set at 5A, pulse on set at 4 μ s, pulse off set at 9 μ s. Minimization of the tool wear on Inconel 600 in EDM, current is set at 5A, pulse on set at 5 μ s, pulse off set at 5 μ s using Taguchi techniques.
- Pulse on is the most significant factor for tool wear in EDM on Inconel 600 followed by interaction of current and pulse on. Pulse on is the most significant factor for surface roughness followed by pulse off using response surface regression.

Table 3—Experimental runs

Trails	C	P on	P off	Results		S/N Ratio	
				SR	TWR	SR	TWR
1	5	4	5	3.251	0.1766	-10.24	15.06
2	5	4	7	3.224	0.07316	-10.17	22.71
3	5	4	9	2.982	0.02644	-9.49	31.55
4	5	5	5	3.728	0.0864	-11.43	21.27
5	5	5	7	3.466	0.0702	-10.80	23.07
6	5	5	9	4.761	0.1204	-13.55	18.39
7	5	6	5	3.527	0.2733	-10.95	11.27
8	5	6	7	5.019	0.025	-14.01	32.04
9	5	6	9	4.363	0.1573	-12.80	16.07
10	10	4	5	3.172	0.0304	-10.03	30.34
11	10	4	7	3.528	0.0271	-10.95	31.34
12	10	4	9	4.237	0.0293	-12.54	30.66
13	10	5	5	2.256	5.1073	-7.07	14.16
14	10	5	7	5.089	0.04013	-14.13	27.93
15	10	5	9	2.748	0.03901	-8.78	28.18
16	10	6	5	6.712	0.5618	-16.54	5.01
17	10	6	7	6.683	0.3511	-16.50	9.09
18	10	6	9	5.286	0.2366	-14.46	12.52
19	15	4	5	4.266	0.10304	-12.60	19.74
20	15	4	7	5.142	0.0642	-14.22	23.85
21	15	4	9	4.11	0.0042	-12.28	47.54
22	15	5	5	2.367	0.3277	-7.48	9.69
23	15	5	7	1.355	0.41396	-2.64	7.66
24	15	5	9	6.101	0.0535	-15.71	25.43
25	15	6	5	6.223	0.91292	-15.88	0.79
26	15	6	7	5.887	0.4322	-15.40	7.29
27	15	6	9	6.634	0.2593	-16.44	11.72

Table 4—Response Table for S/N ratios of TWR and SR

Levels	C	P on	P off
Electrode wear			
1	21.27042	28.08883	11.00065
2	17.87872	16.38422	20.55423
3	17.07889	11.75499	24.67315
Rank	1	2	3
Surface roughness			
1	-11.49	-11.39	-11.36
2	-12.33	-10.18	-12.09
3	-12.52	-14.77	-12.89
Rank	3	1	2

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