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Optimization of EDM Process Parameters on Titanium Super Alloys Based on the Grey Relational Analysis

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Abstract - Electrical discharge machining (EDM) is a unconventional machining process for the machining of complex shapes and hard materials that are difficult of machining by conventional machining process. In this paper deals with the optimization of EDM process parameters using the grey relational analysis (GRA) based on an orthogonal array for the multi response process. The experiments are conducted on Titanium super alloys with copper electrode based on the Taguchi design of experiments L27 orthogonal array by choosing various parameters such as peak current, pulse on time, pulse off time and tool lift time for EDM process to obtain multiple process responses namely Metal removal rate (MRR) and Tool Wear Rate (TWR). The combination of Taguchi method with GRA enables to determine the optimal parameters for multiple response process. Gray relational analysis is used to obtain a performance index called gray relational grade to optimize the EDM process with higher MRR and lower TWR and it is clearly found that the performance of the EDM has greatly increased by optimizing the responses the influence of individual machining parameters also investigated by using analysis of variance for the grey relational grade.

***Keywords*:-- Titanium super alloys, material removal rate tool wear rate, copper electrode, design of experiments and grey relational analysis.**

1. Introduction

Electrical discharge machining (EDM) is one of the most extensively used non-conventional machining process. It uses thermal energy to machine electrically conductive parts regardless of hardness of the material the distinctive advantage of EDM is in the manufacture of mould, die, automotive, aerospace and surgical components. EDM does not make direct contact between the electrode and the workpiece eliminating mechanical stresses, chatter and vibration during machining. The traditional machining techniques are often incapable to machine the titanium super alloys due to its high hardness and these can be machined economically by EDM. Gopala kannan et.al reported the application of combined Taguchi method and grey relational analysis to improve the multiple performance characteristics of Metal removal rate, electrode wear rate and surface roughness in EDM of Aluminum hybrid metal matrix composites[1]. S. Singh et.al investigated optional process parameters using the GRA approach, based on the orthogonal experimental design which minimizes the multiple performance characteristics for APM – EDM of Aluminium hybrid Metal Matrix composite Lin C.L. et. al presented the grey relational analysis based on orthogonal array and fuzzy based Taguchi method for the optimization of the EDM process with multiple process responses and investigated both approaches can improve process responses such as Electrode wear ratio, metal removal rate and surface roughness[3]. Singhs presented the application of the design of experiments and grey relational analysis (GRA) approach to optimize parameters for Electrical Discharge Machining process of 6061 $Al/Al_2O_3P/Zo_p$ Aluminum metal matrix composites the experiments were planned based on an L18 orthogoanl array to determine the optimal setting. The metal removal rate, tool wear rate and surface roughness were selected as the evaluation criteria in the study. The optional combination of process parameters were determined by the gray relational grade obtained through GRA for multiple performance characteristics.

Pradhan et. al studied influence of the various machining process parameter such as peak current, pulse-on-time, dielectric flushing pressure and the duty ratio on the performance criteria like MRR, TWR, overcut and taper while machining Titanium super alloy (Ti – 6A1-4V) on the EDM and found the optimized parameter for MRR with condition larger the better, TWR, OC and taper with condition lower the better by using Taguchi technique which is used for single objective optimization[8] Further more taguchi method with combination ANOVA has been adopted for the optimization of ultrasonic assisted micro – EDM process parameters for each single objective optimization[8]. Taguchi method capable of dealing with single objective optimization[3]. It is difficult to find a single optional combination of EDM process parameters for the performance characteristics as the process parameters influence them differently. Hence the optimization of multiple performance characteristic of EDM process can be efficiently resolved by the GRA technique which is totally different from the traditional statistical analysis. GRA provides an efficient solution to the uncertain, multi input and discrete data problems[7]. G. Kibria and B.R Saker studied the effect of different dielectrics such as Kerosene, deionized water, boron carbide (B_4C) powder suspended Kerosene and deionized water on the performance measures such as MRR, TWR, overcut and diameter variance and surface integrity during machining of Titamium ally (Ti-6A1-4V) and concluded that MRR is high with deionized water dialectric compoared to pure kerosene. TWR is also more when B_4C – mixed. Deionized water is used compared to pure kerosene. In the present paper the investigation is done on the Electrical discharge machining of Titanium super alloy with copper tool electrode , also found the optimized input parameters of Peak current, pulse on time ,pulse off time and tool lift time using Grey relational analysis.

2. Experimental Details

Experiments are carried out on die sinking EDM (shown in fig.2) of type Askar microns model V3525 with servo head constant gap voltage positive polarity. Commercial 30 Grade EDM Oil is used as Dielectric fluid. The investigation has been carried out on Titanium super alloys which has the hardness 104HRC. The chemical composition of work material is given in table.1. The copper electrode(99% of Cu) was used for the experimentation because of higher MMR and lower TWR.. In the present study the effect of the four process parameters has been studied, those are the Pulse Current(I_p), Pulse ON time(T_{on}), Pulse OFF time(T_{off}) and Tool LIFT time(T_{lift}).Machining is carried out for 10 minutes for every experiments and MRR and TWR are calculated for one minute for each experiment. The MRR and TWR are calculated by measuring the weight difference of work piece and electrode before and after machining using a digital weighing balance of type AY220 with precision 0.001gm, is shown in figure 3. The MRR and TWR are calculated as following.

$$MRR = \frac{(wp_1 - wp_2)}{T} \text{ mg/minute}$$

Where wp_1 and wp_2 are the weights of the workpiece before and after machining, T is the machining time.

$$TWR = \frac{(wt_1 - wt_2)}{T} \text{ mg/minute}$$

Where wt_1 and wt_2 are the weights of the workpiece before and after machining, T is the machining time.

The process parameters are selected based on the preliminary experiments and machine operating conditions. Taguchi method is one of the most efficient tools for the analysis of manufacturing design. The design of experiments is based on Taguchi L27(3^4) orthogonal array shown in table 3 is taken for conducting the experiments. The levels and notations of the process parameters are given in table 2. and the experimental results of MRR and TWR tabulated in table 4.

Table.1 Chemical composition of work material.

Titanium	Al	C	Mo	Zr	Si	Fe	P	V
Base	5.5-6.8%	< 0.13%	0.5-2%	1.5-2.5%	< 0.15%	< 0.3%	0.8-2.5%	0.3%

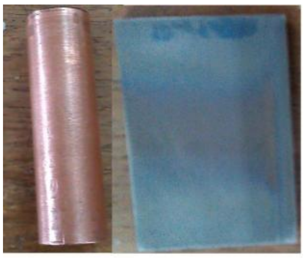
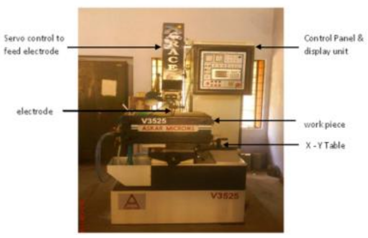


Fig. 1 Tool Electrode & Work Piece



. Fig.2 EDM Machine

Fig. 3 Digital Weighing balance

Table 2: Selected process parameters in EDM process

Factor notation	Factor	Symbol & units	Level 1	Level 2	Level 3
A	Peak Current	I, Amp.	9	12	15
B	Pulse On time	T_{ON}, μs	10	20	50
C	Pulse Off time	T_{OFF}, μs	50	50	100
D	Tool LIFT time	T_{OFF}, μs	5	10	20

Table 3 : L27 Orthogonal array

Sl. No.	Peak Current	Pulse ON time	Pulse OFF Time	Tool Lift Time
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	2
5	1	2	2	3
6	1	2	3	1
7	1	3	1	3
8	1	3	2	1
9	1	3	3	2
10	2	1	1	2
11	2	1	2	3
12	2	1	3	1
13	2	2	1	3
14	2	2	2	1
15	2	2	3	2
16	2	3	1	1
17	2	3	2	2
18	2	3	3	3
19	3	1	1	3
20	3	1	2	1
21	3	1	3	2
22	3	2	1	1
23	3	2	2	2
24	3	2	3	3
25	3	3	1	2
26	3	3	2	3
27	3	3	3	1

3. Results and Analysis

3.1. Grey relational Analysis

Grey relational Analysis (GRA) Technique is used to solve the problems of the systems that are complex and multivariate. GRA is a alternate method for traditional statistical methods which deals with the small sample size and uncertainty conditions and can be applied in optimization of multiple quality characteristics [4]. GRA is normalization based evolution technique in which the quality characteristics of the measured data are first normalized ranging from 0 to 1. This process is known as grey relational generation. In the present study, normalization of the experimental results obtained for metal removal rate, Tool wear rate in the range between 0 and 1.

Table 4 : Experimental Results obtained for MRR and TWR

Sl. No.	MRR (mg/min)		TWR(mg/min)	
	1	2	1	2
1	9	7.2	1.50	1.20
2	4.9	3.3	0.60	0.50
3	1.5	2.1	0.60	0.50
4	12.4	12.81	0.30	0.48
5	8.6	7.93	0.20	0.11
6	5.3	5.6	0.26	0.16
7	10.1	7.8	0.23	0.13
8	13.2	10.9	0.50	0.42
9	7.7	8.0	0.20	0.17
10	9.1	8.7	0.90	0.70
11	3.8	4.0	0.30	0.31
12	3.4	3.5	1.23	1.12
13	7.3	6.5	0.73	0.69
14	12.8	11.6	0.20	0.18
15	6.1	5.6	0.30	0.28
16	12.7	11.8	0.40	0.41
17	10.8	11.1	0.30	0.40
18	5.2	4.9	0.10	0.90
19	8.6	8.0	1.10	1.00
20	10.9	10.2	1.20	1.30
21	4.9	4.4	0.90	0.80
22	24.3	21.2	3.30	3.00
23	17.4	17.0	2.20	1.70
24	7.7	7.1	0.70	0.80
25	11.13	10.7	0.73	0.80
26	8.7	8.3	0.93	0.86
27	14.4	13.9	1.10	1.30

In the GRA to get the normalized values of "larger the better" type performance characteristics such as MRR with i^{th} experimental run j^{th} response for each replication k is expressed as follows

$$x_{ijk} = \left[\frac{\eta_{ijk} - \min \eta_{ijk}}{Max\eta_{ijk} - Min\eta_{ijk}} \right]$$

For "lower the better" type performance variable such as tool wear rate i.e. tool wear rate. The normalized value is expressed as

$$x_{Ijk} = \left[\frac{Max\eta_{Ijk} - \eta_{ijk}}{Max\eta_{ijk} - Min\eta_{ijk}} \right]$$

For i = 1, 2, ……… 27, j = 1, 2 and k =1,2.

Where x_{ijk} is normalized value after grey rational generation, η_{ijk} is experimental value of i^{th} experiment in j^{th} response for k^{th} replication, Minη_{ijk} is the smallest value of η_{ijk} , Maxη_{ijk} is the largest value of η_{ijk}

Normalization involves, the transferring the original sequence to the comparable sequence. The normalized data for each of the response of the process output i.e., MRR & TWR are furnished in Table 5.

3.2. Grey relational co-efficient

After normalization the reference sequence is identified from jth reponse in k^{th} replication is called the ideal normalized result for the each response characteristics [7]. Normalization creates a new matrix. From this matrix the reference sequence is identified which is maximum of the normalized values then GRC is calculated between the desired and actual experimental data.

The Grey relational co-efficient of i^{th} experiment for j^{th} response in the k^{th} replication is expressed as ξ_{ij} .

$$\xi_{ijk} = \frac{\beta_{\min} + \phi\beta_{\max}}{\beta_{ijk} + \phi\beta_{\max}}$$

Where β_{jk} is absolute value of the difference between Ideal sequences x_{ojk} and x_{ijk} , ϕ is the distinguishing coefficient in the range of 0 to 1. GRC is calculated by selecting proper distinguishing coefficient generally ϕ = 0.5 is accepted [10]. In the present study same was considered. The Grey relational coefficients for MRR and TWR and Grey relational grade (GRG) are shown in table 6.

Table 5: Normalization of Experimental results (Grey Relational Generation)

Sl. No.	MRR Normalized		TWR Normalized	
	1	2	1	2
1	0.3289	0.2670	0.5625	0.6185
2	0.1491	0.0628	0.8437	0.8591
3	0.00	0	0.8437	0.8591
4	0.4780	0.5607	0.9375	0.8659
5	0.3114	0.3052	0.9687	0.9931
6	0.1666	0.1832	0.9500	0.9759
7	0.3771	0.2984	0.9593	0.9862
8	0.5131	0.4607	0.8750	0.8866
9	0.2719	0.3089	0.96875	0.9725
10	0.3333	0.3455	0.7500	0.7903
11	0.1008	0.0994	0.9375	0.9244
12	0.0833	0.0733	0.6468	0.6460
13	0.2543	0.2303	0.8031	0.7938
14	0.4956	0.4974	0.9687	0.9690
15	0.2017	0.1832	0.9375	0.9347
16	0.4912	0.5078	0.9063	0.8900
17	0.4078	0.472	0.9375	0.8934
18	0.1622	0.1466	1	1
19	0.3114	0.3089	0.6875	0.6873
20	0.4122	0.4240	0.6563	0.5842
21	0.1491	0.1204	0.7500	007560
22	1.00	1	0	0
23	0.6973	0.7801	0.3437	0.4467
24	0.2719	0.2617	0.8125	0.7560
25	0.4224	0.4502	0.8031	0.7560
26	0.3157	0.3246	0.7406	0.7353
27	0.5657	0.6178	0.6875	0.5842

The overall multiple performance characteristics is based on the Grey relational grade, which is obtained by integrating the Grey relational coefficients corresponding to each experiment. All grey relational grades are calculated as.

$$\gamma_i = \frac{1}{m} \sum_{i=1}^{m} \xi_{ijk}$$

Where m is the no of process responses, γi is the grey rational grade for the i^{th} experiment.

The GRG is used to analyze the relational degree of multiple response characteristics. Higher the grey relational grade represent a stronger relational degree between the ideal normalized value x_{ok} and the given sequences x_{ijk} [3]. The optimization of the complicated multiple process responses can be converted into optimization of single grey relational grade. Since the experiments are carried out on the basis of orthogonal experimental design which was designed by Tagachi. The effect of each level of the process parameters on the GRG can be independent. Table 8 shows the mean of the GRG for each level of the EDM process parameters[1] and the average of the grey relational grade.

Table 6: Grey relational Coefficients, Grey grade

Sl. No.	GRC				GRG
	MRR1	MRR2	TWR1	TWR2	
1	0.4269	0.4055	0.5333	0.5672	0.4832
2	0.3701	0.3478	0.7618	0.7802	0.5649
3	0.3333	0.3333	0.7618	0.7801	0.9092
4	0.4892	0.5323	0.888	0.7885	0.6747
5	0.4206	0.4185	0.9411	0.9863	0.6916
6	0.3749	0.3797	0.909	0.9541	0.6544
7	0.4452	0.4161	0.924	0.9731	0.6897
8	0.5066	0.4811	0.8	0.8151	0.6507
9	0.4071	0.4197	0.9411	0.9478	0.6789
10	0.4285	0.4312	0.6667	0.7045	0.5577
11	0.3573	0.3569	0.8888	0.8686	0.6179
12	0.3529	0.3504	0.586	0.5855	0.4687
13	0.4014	0.3938	0.7175	0.708	0.5552
14	0.4978	0.4987	0.9411	0.941	0.7198
15	0.3851	0.3797	0.8888	0.8845	0.6345
16	0.4956	0.5039	0.8422	0.8196	0.6653
17	0.4578	0.4863	0.8888	0.8242	0.6643
18	0.3737	0.3694	1	1	0.6857
19	0.4206	0.4197	0.6154	0.6152	0.5177
20	0.4596	0.4647	0.5926	0.5459	0.5157
21	0.3701	0.3624	0.666	0.672	0.5177
22	1	1	0.3333	0.3333	0.6666
23	0.6228	0.6257	0.4324	0.4746	0.5388
24	0.4071	0.4037	0.7272	0.672	0.5525
25	0.4639	0.4763	0.7175	0.672	0.5824
26	0.4222	0.4253	0.6584	0.6538	0.5399
27	0.4691	0.5667	0.6154	0.5459	0.5492

3.3. Analysis of Variance

Analysis of variance(ANOVA) is used to find out which process parameters significantly affect the process response. The results of the ANOVA are shown in table 7. The F-test is used to determine which process parameters have a significant effect on the process response, when the F-value is large the change of process parameters has a significant effect on the process response. The results of the ANOVA shows that the peak current is the significant process parameter and pulse on time, pulse off time, tool lift time are the insignificant process parameters effecting the multiple process response. Fig 4 shows the grey relational graph to the mean response for overall grey relational grade, larger the grey relational grade, the better is the multiple process response. Hence the optimal machining parameters are pulse current at level 1, pulse on time at level 3, pulse off time at level 3 and tool lift time at level 3. i.e., A1B3C3D3.

3.4. Confirmation test

Once the optimal levels of EDM process parameters obtained, these parameters are used to predict the grey relation grade that represent the quality of the EDM process. Predicted grey relational grade is calculated as.

$$\gamma_{predicted} = \gamma_m + \sum_{i=1}^{n} (\gamma_0 - \gamma_m)$$

Where $\gamma_{predicted}$ is grey relational grade to validate the EDM process, γ_0 is the average grey relational grade of optimal level of the factors. γ_m is the average grey relational grade and *n* is the number of factors. Finally the confirmation tests are conducted using the optimal EDM process parameters combination i.e., A1B3C3D3 for two trial. The average responses of MRR & TWR obtained from the confirmation experiments are 7.7 mg/min and 0.2 mg/min respectively.

Table 7: Analysis of Variance Results at 95% confidence level

Source of Variation	Sum of Square	D OF	Mean sum of square	F –Ratio calculated	F – Ratio Table	Remarks
A	0.5795	2	0.028975	3.82558	3.55	Significant
B	0.02201	2	0.011005	1.45299	3.55	Inignificant
C	0.00376	2	0.00188	0.24822	3.55	Insignificant
D	0.01	2	0.005	0.66015	3.55	Insignificant
Error	0.136334	18	0.007575			
Total	0.230054	26				

Table 8: The Mean response table for the overall grey relational grade

Level	I	TON	TOF	T LIFT
1	**0.66636**	0.5725	0.5991	0.5971
2	0.6187	0.632	0.6115	0.6015
3	0.5533	**0.634**	**0.6278**	**0.6399**
Average of the Grey Relational Grade = 0.6179				

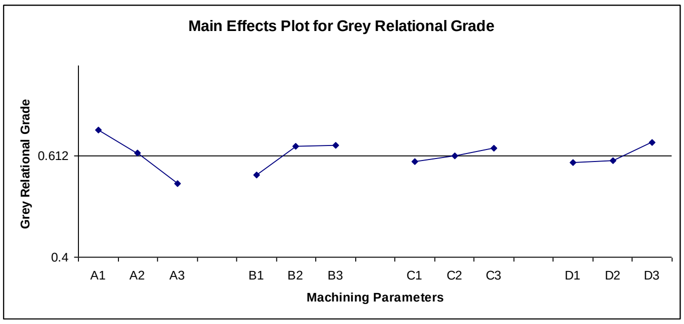


Fig. 4 Grey Relational Graph

Table 9: Results of performance measures for initial and optimal process parameters

	Initial Machining Parameters	Optimal Machining Parameters	
		Predicted	Experimental
Combination level	A2B1C2D3	A1B3C3D3	A1B3C3D3
MRR mg/min	3.9	12.0	7.7
TWR mg/min	0.3	0.71	0.25
Predicted Grey Relational Grade = 0.7129			

The table 9 shows the comparison of multiple process responses for initial and optimal machining parameters. The metal removal rate increased from 3.9 mg/min to 7.7 mg/min and TWR decreased from 0.3 mg/min to 0.2mg/min It is clearly shows that the MRR and TWR are improved greatly.

4. Conclusion

In this paper presented the application of Grey relational analysis coupled with Taguchi design of experiments After applying the Grey relational method based on L27 orthogonal array, it is observed that the MRR increased and TWR decreased which are positive indicators of machining efficiency in the machining process, hence it can be concluded that this method is most suitable for the parametric optimization of EDM process and also the results of ANOVA shows that the pulse current is the most influencing factor for machining of Titanium super alloys.

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