**Parametric otimization of Electrical Discharge Grinding on**

**Ti-6Al-4V alloy using Response Surface Methodology**

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**Abstract**

In this paper, an experimental study of the grinding wheel effect on material removal rate (MRR) and surface roughness (SR) of electro discharge grinding (EDG) process of Ti-6Al-4V alloy through response surface methodology (RSM). Wheel speed (WS), discharge current (Ip), pulse on time (Ton) and pulse off time (Toff) are considered as the important factors. An experimental plan for RSM-central composite design (CCD) of four parameters with three levels has been employed. Analysis of variance (ANOVA) has been employed to identify the significance of the process parameters on the performances characteristics of MRR and SR. ANOVA results was performed to identify the significant parameters and the establishing the mathematical model of MRR and SR. Furthermore, mathematical models and experimental values were correlated; the results were verified and found to be within the range of 7.57% and 4.62% of MRR and SR respectively.

***Keywords:*** *Electrical Discharge Grinding, Ti-6Al-4V alloy, Response Surface Methodology, Analysis of Variance*

1. **Introduction**

EDM is thermo-electric machining processes in which the electrode and workpiece do not come into direct contact, and eliminates the mechanical stress, chatter and vibration problems during machining [1]. Nowadays, EDM process for used in various advanced materials such as composites, ceramics, HSTR steels, Nickel and Titanium. Selection of control factors plays an significant role in EDM; which effects the performance characteristics resulting in lower MRR and high rate of tool wear rate (TWR) and surface and sub surface damage creation of thin and brittle heat affected zone(HAZ). In order to overcome these EDM limitations a hybrid EDM process is used. One of the unconventional hybrid techniques is electrical discharge grinding (EDG). EDG was developed by replacing the stationary electrode used in EDM with rotating electrode. In EDG process, an electrically conductive disk shape is used as a tool electrode at horizontal axis instead of stationary tool electrode. The rotation of disc wheel, the flushing efficiency enhanced between discharge gap. Due to the dielectric flushining affects results enrichment in MRR, lower the surface finish and HAZ [2-3].

Many attempts have been made by different researchers regarding applications of EDG for different work piece materials and performance in terms of MRR, SR and TWR. Chandrasekhar et al. fabricated a self made an experimental setup of EDG in face grinding type. The considered process parameters such as Ip, Ton, Toff, and wheel rotations per minute (RPM) on performance characteristics MRR and SR during machining of high carbon steel (HCS) and high speed steel (HSS) work pieces [4]. The result was observed that MRR enhances with enhance in WS for both HCS and HSS. The MRR is high at while machining the HCS workpiece compared to the HSS workpiece for the same parameter settings. Yadav et al. conducted experiments on self-developed electrical discharge diamond cut-off grinding (EDDCG) of Ti-Al-Mo-V alloy. They found that the MRR increases with an increase in wheel RPM, Ip and Ton [5]. Modi et al. examined the experimental study on Ti-6Al-4V alloy with in-house developed Powder Mixed Electro Discharge Diamond Surface Grinding (PMEDDSG). It concluded that better surface finish and higher MRR obtained at PMEDDSG [6]. Shih et al. investigated the EDG using a rotary disk to mimic the machining process of a surface grinder with horizontal spindles of cold worked tool steel AISI D2. The results concluded that lower EWR and higher MRR were obtained at rotary disk electrode when positive polarity was considered [7].

Singh et al. optimized the EDM parameters to improve the surface finish of Titanium Alloy adopted the Taguchi’s technique. Ton, Toff and Ip were considered as parameters, copper tool used as an electrode material. It concluded that Ip and Ton has a significant effect on SR [8]. Shu et al. investigated the performance characteristics of EDG on metal matrix composite (MMC) electrode (Cu/SiCp). It was concluded that MRR enhanced 3to7 times compared to the without attachment of EDM. Electrode rotating speed, SiCp particles size and Ip were significant parameters of MRR [9]. Mohan et al. studied the EDM process parameters of Al-SiC MMC with rotary tube electrode. The considered factors were polarity, Ip, electrode material, pulse duration, and rotation of electrode on performance characteristics like MRR, TWR, and SR. The increased the electrode speed resulted in positive effect with MRR, TWR, SR than the stationary electrode material [10].

The literature survey reveals that most of the researchers have concentrated on the experimental setup of EDM process; it was observed that a scarce amount of research focuses on EDG with parameters optimization of Ti-6Al-4V alloy with RSM approach. WS, Ip, Ton and Toff are the EDG variable factors. So, the main objective of the present work is to maximize the MRR and minimize the SR using the EDG factors adopted the design of experiments (DoE). The experiments were planned and conducted by using RSM-CCD approach. ANOVA analysis was conducted to finalise the significant parameters and interaction; and to develop empirical relation.

1. **Experimental Setup**

The EDG attachment has been used on EDM Formatics 50 Machine (Make. India). The EDG setup has been placed on the ram of the EDM machine. The experimental setup is shown in Figure1. The EDG setup consists of electrically conductive rotating non-abrasive grinding wheel (brass), motor, shaft, belt, pulley, and bearing. The brass with dimensions of 100mm diameter and 10 mm thickness is used as the grinding wheel. The fabricated attachment has replaced by the original tool holder of die-sinking EDM. The EDG assembly is partially dipped in a dielectric within the dielectric tank [2].

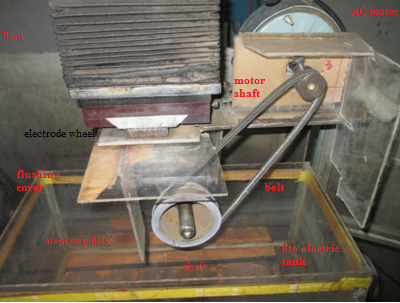
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Fig. 1. Grinding wheel setup attached the EDM machinine

The WS, Ip, Ton and Toff are the process parameters of the EDG process. The variable factors and their ranges are observed in Table 1. Ti-6Al-4V alloy is selected as a workpiece material for the experimentation. Ti-6Al-4V alloy of dimensions 100x50x5 mm are taken. Drinking water was used as a dielectric fluid. The experiments were conducted for a fixed time period i.e 15 min. To calculate the MRR, weight differences are measured by electronic digital weighing machine (Make: citizen, India) having least count 0.0001gm. Machining time was measured by the EDM machine time counter. Surface finish was measured using handy surf (Make: Zeiss, India).

1. **Design of experiments**

Response surface methodology (RSM) is a statistical technique for representing optimum variable factors and developing response performance measures i.e. MRR, and SR. In this paper RSM central composite design (CCD) was used. CCD is the most popular among the various classes of RSM design due to its flexibility, ability to run sequentially and efficiency in providing the overall experimental error in minimum number of runs. In CCD, each factor is varied at three levels (-1, 0, 1) for developing a second order model as given in equation (1). When the number of factors (k=4) or greater, it is not necessary to run all combination of factors [14-15]. The factors part of the design can be run using a fraction of total number of available combinations. The possible design options can either be regular factional factorials or minimum run resolution.

--------------------------------(1)

Where, is constant, are linear coefficient, quadratic and interaction coefficients. The RSM models were developed for the sustainable measures of optimum response values using Design expert® 11.0 statistical software. The aim is to identify the best response values and these are influenced by variable dependent factors from the DoE. The considered factors are WS, Ip, Ton and Toff. The smooth functions in the RSM that enhances the convergence of the optimization factors. And also gives us maximum yield and minimum cost, the following output factors which are modeled by using polynomial second order equation.

Table 1 Variable factor and their levels

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variable** | **Coding** | **Level 1** | **Level 2** | **Level 3** |
| **-1** | **0** | **1** |
| Wheel speed (rpm) | WS (A) | 400 | 550 | 700 |
| Current(Amp) | Ip(B) | 10 | 15 | 20 |
| Pulse on time(µs) | Ton(C) | 25 | 45 | 65 |
| Pulse off time (µs) | Toff(D) | 24 | 36 | 48 |

1. **Results and Discussion**

Experiments are planned and conducted according to RSM-CCD layout. The experimental layout and their result for MRR and SR are observed in the Table 2. The results was analyzed using Design of expert® 11.0 statistical software.

**4.1 ANOVA and mathematical model for MRR (mm3/min)**

The MRR results of the quadratic model which was analyzed using ANOVA has exposed that there are many insignificant terms in the model. Therefore, model reduction using the backward elimination process has been performed to improve the model. It eliminates the insignificant terms in order to adjust the fitted quadratic model while maintaining the hierarchy of the model. The model F value of 551.75 with its Prob> value less than 0.0001 indicates that the model is significant for MRR.

The values of prob>F less than 0.05 indicates the significant of the model terms. Values which are greater than 0.1000 indicate that the model terms are not significant. In this MRR model, WS,Ip,Ton,WS\* Ip, WS \* Ton, Ip\*Ton, Ip\*Toff, and WS2,Ip2, and Ton2, are significant model terms. It indicates that the most significant parameters for MRR are WS,Ip,Ton and WS\*Ton.

The lack of fit F values of 4.6281 implies the model to fit with the experimental data. When it approaches to unity, the response model fits better to the experimental (actual) data and shows less variation between the predicated and actual values. The values of R2 and R2 (pred.) for MRR models are 0.9980 and 0.9962, respectively (Table 4). From the Table 3 and 4 observed the ANOVA and modeling statistical summary results for MRR. Response surface plots on the MRR observe in the Fig. 2.

Table 2 Experimental plan and their results values

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Std.ord | Run ord | WS(RPM):  A | IP(Amp):  B | Ton (**µs**):  C | Toff (**µs**):  D | **MRR**  (mm3/min) | SR(**µm**) |
| 1 | 5 | 400 | 10 | 25 | 24 | 4.7911 | 5.70 |
| 2 | 16 | 700 | 10 | 25 | 24 | 6.1670 | 5.40 |
| 3 | 25 | 400 | 20 | 25 | 24 | 10.0312 | 6.20 |
| 4 | 21 | 700 | 20 | 25 | 24 | 13.7162 | 6.00 |
| 5 | 30 | 400 | 10 | 65 | 24 | 10.3703 | 7.56 |
| 6 | 11 | 700 | 10 | 65 | 24 | 15.0429 | 6.10 |
| 7 | 9 | 400 | 20 | 65 | 24 | 32.2573 | 7.95 |
| 8 | 2 | 700 | 20 | 65 | 24 | 40.7720 | 6.80 |
| 9 | 3 | 400 | 10 | 25 | 48 | 6.7923 | 5.75 |
| 10 | 10 | 700 | 10 | 25 | 48 | 7.3725 | 5.10 |
| 11 | 17 | 400 | 20 | 25 | 48 | 9.4131 | 6.30 |
| 12 | 6 | 700 | 20 | 25 | 48 | 13.1624 | 5.80 |
| 13 | 1 | 400 | 10 | 65 | 48 | 11.6365 | 8.00 |
| 14 | 12 | 700 | 10 | 65 | 48 | 16.0687 | 7.00 |
| 15 | 29 | 400 | 20 | 65 | 48 | 32.7146 | 8.30 |
| 16 | 23 | 700 | 20 | 65 | 48 | 39.3417 | 7.20 |
| 17 | 20 | 400 | 15 | 45 | 36 | 14.1923 | 7.10 |
| 18 | 15 | 700 | 15 | 45 | 36 | 19.5938 | 6.20 |
| 19 | 24 | 550 | 10 | 45 | 36 | 6.8660 | 7.60 |
| 20 | 13 | 550 | 20 | 45 | 36 | 19.5175 | 8.40 |
| 21 | 28 | 550 | 15 | 25 | 36 | 8.9880 | 6.30 |
| 22 | 19 | 550 | 15 | 65 | 36 | 22.7389 | 7.70 |
| 23 | 27 | 550 | 15 | 45 | 24 | 14.2646 | 5.90 |
| 24 | 7 | 550 | 15 | 45 | 48 | 14.4175 | 6.35 |
| 25 | 14 | 550 | 15 | 45 | 36 | 14.3194 | 6.90 |
| 26 | 26 | 550 | 15 | 45 | 36 | 14.1125 | 6.90 |
| 27 | 18 | 550 | 15 | 45 | 36 | 14.8088 | 7.05 |
| 28 | 22 | 550 | 15 | 45 | 36 | 14.6985 | 7.10 |
| 29 | 8 | 550 | 15 | 45 | 36 | 14.8915 | 7.10 |
| 30 | 4 | 550 | 15 | 45 | 36 | 14.6914 | 7.00 |

**Regression equation for MRR:** In terms of actual factors, second order regression equation for the performance characteristic of MRR in terms of input process parameters can be expressed by the following equation.

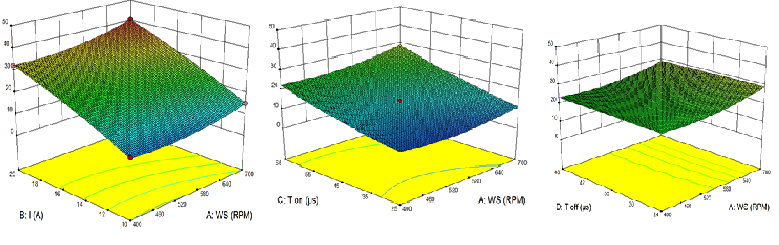
MRR= +32.35407-0.12748\*WS +0.73158\*Ip -0.74433\*Ton+0.27612\*Toff +9.59485E-004\* WS\*Ip+3.09484E-004\*WS\*Ton-9.93132E-005\*WS\*Toff+0.044229\*Ip\*Ton-7.96310E-003\*Ip\*Toff-1.86766E-004\*Ton\*Toff+1.06543E-004\*WS^2-0.052164\*Ip^2+3.41898E-003\*Ton^2-1.07507E-003\* Toff ^2

Table 3 Model summary statistics for the MRR

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Source** | **Std.**  **Dev.** | **R-Squ** | **Adjusted**  **R-Squ** | **Predicted**  **R-Squ** | **Press** | **Recommended** |
| Linear | 3.9514 | 0.8408 | 0.8153 | 0.7222 | 681.1041 |  |
| 2FI | 1.6397 | 0.9791 | 0.9682 | 0.9384 | 150.8365 |  |
| Quadratic | 0.5628 | 0.9980 | 0.9962 | 0.9911 | 21.79117 | Suggested |
| Cubic | 0.3555 | 0.9996 | 0.9985 | 0.9586 | 101.3182 | Aliased |

Table 4 ANOVA results for the MRR

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Source** | **Sum of SS** | **DoF** | **Mean SS** | **F-Value** | **P-Value Pro>F** | **Recommended** |
| Model | 2447.271 | 14 | 174.8051 | 551.7537 | 1.02E-17 | Significant |
| A-WS | 84.67147 | 1 | 84.6715 | 267.2566 | 5.73E-11 |  |
| B-I | 879.4751 | 1 | 879.4751 | 2775.9700 | 1.93E-18 |  |
| C-T on | 1096.842 | 1 | 1096.8420 | 3462.0650 | 3.71E-19 |  |
| D-T off | 0.683701 | 1 | 0.6837 | 2.1580 | 0.162485 |  |
| AB | 8.285503 | 1 | 8.2855 | 26.1523 | 0.000127 |  |
| AC | 13.79235 | 1 | 13.7924 | 43.5340 | 8.47E-06 |  |
| AD | 0.511304 | 1 | 0.5113 | 1.61388 | 0.2233 |  |
| BC | 312.9925 | 1 | 312.9925 | 987.9280 | 4.18E-15 |  |
| BD | 3.652475 | 1 | 3.6525 | 11.5286 | 0.003995 |  |
| CD | 0.032147 | 1 | 0.0321 | 0.1014 | 0.754468 |  |
| A^2 | 14.88915 | 1 | 14.8892 | 46.9960 | 5.46E-06 |  |
| B^2 | 4.406365 | 1 | 4.4064 | 13.9082 | 0.002014 |  |
| C^2 | 4.845785 | 1 | 4.8458 | 15.2952 | 0.00139 |  |
| D^2 | 0.062094 | 1 | 0.0621 | 0.1959 | 0.664292 |  |
| Residual | 4.752257 | 15 | 0.3168 |  |  |  |
| Lackof Fit | 4.290228 | 10 | 0.4290 | 4.6428 | 0.052004 | not significant |
| Pure Error | 0.462029 | 5 | 0.0924 |  |  |  |
| Cor Total | 2452.023 | 29 |  |  |  |  |



**Fig.2** Response surface plots shows the two variable on MRR (WS:Ip, WS:Ton and WS:Toff)

**4.2 ANOVA and mathematical model for the SR (µs)**

As a result, quadratic model is statistically significant; the backward elimination process was used. It eliminates the insignificant terms in order to adjust the fitted quadratic model while maintaining the hierarchy of the model. The model F value of 86.74 with its Prob> value less than 0.0001 indicates that the model is significant for SR. The values of prob>F less than 0.0500 indicates the significant of the model terms. Values which are greater than 0.1000 indicate that the model terms are not significant.

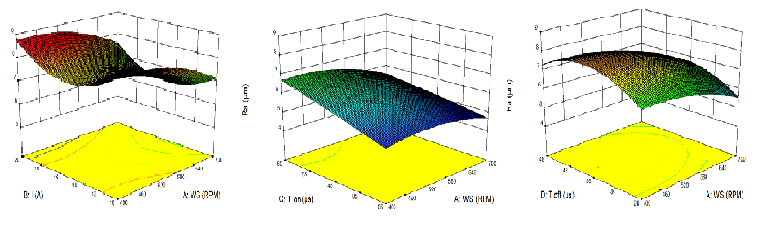
In this SR model, WS,Ip,Ton,Toff, WS\*Ip, WS\*Ton, WS\*Toff, Ip\*Ton, Ip\*Toff, Ton\*Toff and WS 2, Ip 2, Ton 2, and Toff 2 are significant model terms. The model indicated that the most significant terms for SR are WS,Ip,Ton,Toff, WS\*Ton, Ton\*Toff and WS2, Ip2and Toff 2. The lack of fit F value of 2.65 implies the model to fit with the experimental data. When it approaches to unity, the response model fits better to the experimental (actual) data and shows less variation between the predicated and actual values. The values of R2 and R2 (pred) for SR models are 0.9878 and 0.9764, respectively. From the Table 5 and 6 found the ANOVA and modeling statistical summary results for SR. Response interaction plots shows the two input parameters on the SR observe in the Fig. 3.

Table 4 ANOVA results for the SR

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Source** | **Sum of SS** | **DoF** | **Mean SS** | **F-Value** | **P-Value Pro>F** | **Recommended** |
| Model | 21.4447 | 14 | 1.5318 | 86.7392 | 9.53E-12 | Significant |
| A-WS | 2.9282 | 1 | 2.9282 | 165.8148 | 1.64E-09 |  |
| B-I | 1.2482 | 1 | 1.2482 | 70.6817 | 4.65E-07 |  |
| C-T on | 10.9824 | 1 | 10.9824 | 621.9001 | 1.26E-13 |  |
| D-T off | 0.2544 | 1 | 0.2544 | 14.4071 | 0.001759 |  |
| AB | 0.0132 | 1 | 0.0132 | 0.7489 | 0.400457 |  |
| AC | 0.5852 | 1 | 0.5852 | 33.1395 | 3.79E-05 |  |
| AD | 0.0012 | 1 | 0.0012 | 0.0694 | 0.795843 |  |
| BC | 0.0361 | 1 | 0.0361 | 2.0442 | 1.73E-01 |  |
| BD | 0.0121 | 1 | 0.0121 | 0.6852 | 0.420782 |  |
| CD | 0.3721 | 1 | 0.3721 | 21.0709 | 0.000354 |  |
| A^2 | 0.4169 | 1 | 0.4169 | 23.6084 | 2.08E-04 |  |
| B^2 | 2.3327 | 1 | 2.3327 | 132.0926 | 7.78E-09 |  |
| C^2 | 0.0068 | 1 | 0.0068 | 0.3837 | 0.54492 |  |
| D^2 | 2.3439 | 1 | 2.3439 | 132.7284 | 7.53E-09 |  |
| Residual | 0.2649 | 15 | 0.0177 |  |  |  |
| Lack of Fit | 0.2228 | 10 | 0.0223 | 2.6472 | 0.147081 | not significant |
| Pure Error | 0.0421 | 5 | 0.0084 |  |  |  |
| Cor Total | 21.7096 | 29 |  |  |  |  |

Table 5 Model summary statistics for the SR

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Source** | **Std.**  **Dev.** | **R-Squ** | **Adjusted**  **R-Squ** | **Predicted**  **R-Squ** | **Press** | **Recommended** |
| Linear | 0.5018 | 0.7099 | 0.6635 | 0.6059 | 8.5555 |  |
| 2FI | 0.5269 | 0.7569 | 0.6290 | 0.5144 | 10.5414 |  |
| Quadratic | 0.1328 | 0.9877 | 0.9764 | 0.9263 | 1.5987 | Suggested |
| Cubic | 0.0939 | 0.9971 | 0.9882 | 0.8112 | 4.0972 | Aliased |

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**Fig.3** Response surface plots shows the two variable on SR (WS:Ip, WS :Ton and WS :Toff)

1. **Conclusion**

The present work has successfully established development of EDG attachment and studied the effect of input parameter on response characteristic. A model is prepared by RSM. The conclusions was drawn from the present work are as follows.

* Higher MRR was found at Ip,Ton and WS are at maximum of their level.
* Lower SR was found at minimum levels of Ip, WS and Toff .
* The fit summary recommended that the quadratic models are statistically significant for analysis of MRR and SR.
* MRR was observed through ANOVA results, Ton and Ip are the most influential parameters than the reaming parameters.
* SR was found from the ANOVA results, Ton is the most dominated parameter among the four parameters.
* The empirical equations for the MRR and SR were formed through the RSM-CCD approach and then found the error between experimental and predicated values are lie with in 7.57% and 4.62%, respectively.

**References**

1. K.H. Ho and S.T. Newman, Int J Mach Tools Manuf, 43,1287-1300, (2003).
2. A.S. Sahu, M.Kolli, G.V.Rao and A. Kumar, International Colloquium on Materials, Manufacturing and Metrology, ICMMM, (2014), Aug 8-9, IIT Madras, IIT, Chennai, India.
3. M. Kolli and A.Kumar, Mat in Tech, 50, 229-238, (2016).
4. A.B. Chandrasekhar, V.Yadava and G.K.Singh, Mat and Manf Proc, 25, 482-487, (2010).
5. S.Yadav and V.Yadava, Mat and Manf Proc, 28, 557-561, (2010).
6. M.Modi, and G.Agarwal, Adv Mat Res Jou of Mech Eng, 59,12,725-747, (2013).
7. H.R. Shih, K.M.Shu, Int Jou of Adv Manu Tech, 38,59- 67, (2008).
8. S.K.Singh and N. Kumar, Int Jou of Eme Sci and Tech, 10, 2016-2023, (2013).
9. K.M. Shu and G.C. Tu, Int Jou of Man Tools and Manu, 43, 845-854, (2003).
10. Mohan, Rajadurai and K.G. Satyanarayana, Jou of Mat Proc Tech, 124, 297-304,(2002).