International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-5, March 2020

Tool Wear Rate on Inconel 718 using W-Powder Mixed Electric Discharge Drilling

J. Jeevamalar, R. Vimalraj, M. Vigneshwaran, G. Vignesh

Abstract*: Electrical Discharge Drilling (EDD) is an unconventional manufacturing process with large industrial performances. Addition of powder particles in dielectric changes some process variables and machines hard and hard to cut materials with greater surface finish high tolerance and accuracy to accomplish a superior material removal rate with a reduced Tool Wear Rate (TWR). This research work explores the performance of TWR on Tungsten Powder Mixed Electrical Discharge Drilling (W-PMEDD) on Inconel 718 super alloy. The input machining parameters of Peak Current (I_p) Pulse on (T_{on}) and Pulse off time (T_{off}) and the output measure of TWR were examined by Response Surface Method (RSM). Analysis of Variance was used to evaluate the effect of the machining parameters and it is concluded that I_p, T_{on} and T_{off} are the most significant parameters while machining of W-PMEDD on Inconel 718.

Keywords*: Inconel 718, Electrical Discharge Drilling, ANOVA, Tool Wear Rate and Response Surface Method.

I. INTRODUCTION

Electrical Discharge Drilling is and advanced method of machining; where electrical energy is used to build electrical sparlke, and the sparkle heat energy is used to remove the material. Due to their hardness and heat resistance, high strength to weight ratio, it machines hard and hard to cut materials that are used in nuclear, aerospace engineering and other applications. EDD is extensively used for producing moulds, dies, tools and new precision components. It replaces traditional machining methods such as drilling, milling, and grinding. The latest advanced process is Powder Mixed Electrical Discharge Drilling which is used to get a better surface finish of the machined workpiece. The addition of powder particles like SiC, Al_2O_3 to a dielectric has an additional benefit for enhancing surface quality by reducing micro-cracks.

Inconel 718 is a Nickel based High-Strength and high-Temperature Resistant (HSTR) superalloy. It is used in aviation applications, for example, Rocket Motors, Gas Turbines, Space Crafts, Tooling, and Pumps. The modern machining method is not favoured because of its low thermal conductivity, high durability, high stiffness, and high strength rate of work. Due to its rapid demand in high-temperature applications and less literature works available on EDD of this superalloy, Inconel 718 was chosen for this job. In the present paper, the work was done out to find the influences of parameters settings, which may yield minimum TWR. It is important to know the history and current status of the EDD process to suggest future areas of work. A broad literature survey has been carried out to find the state of art at the EDD process. EDD offers and efficient production method that makes it possible to manufacture parts that are made from hard materials with complex geometry that are not easy to machine by traditional machining processes.

Jain [1] employed r-EDM to drill accurate blind holes in carbon steel and examined the impact of T_{on}, electrode diameter, and depth of diffusion in high-speed steel. Soni [2] implemented rotary as well as sinking EDM processes for creating of holes in Ti-alloy with Cu-W electrode and compared the results of both mechanisms in terms of MRR, TWR and SR by varying I_p and the rotational speed of the tool. It is established that MRR increases in the case of the rotating tool because flushing and spark efficiency during the process was increased. On the other hand, due to the rotation, SR and TWR increased as the speed of the tool is increased. Mohan et al [3]. employed a hollow tool for drilling holes in Al-SiC metal matrix composite alloy using rotating EDM. Significant improvements in MRR, SR, and TWR were achieved owing to the rotating tool. Later, the authors found that employing cooling techniques on the electrode has decreased the TWR [4]. Abdulkareem et al. [5] made an experimental investigation by implementing a cooling technique to a Cu electrode during EDM of Ti- alloy (Ti-6Al-4V) in the presence of kerosene dielectric. Experimental results confirmed that maximum reduction in TWR (27%) and considerable enhancement in SR (8%) was realized by this cooling process as compared to sinking EDM. Kolli & Kumar [6] employed Gr-powder with surfactant in the machining of Ti-alloy and observed that there is an abridged thickness of recast layer, SR and increased MRR. Teimouri & Baseri [7] proposed a rotating magnetic field dry EDM using Ant Colony Optimization Technique. Gholipoor et al.

Revised Manuscript Received on March 30, 2020.
* Correspondence Author
Dr. J.Jeevamalar*, Associate Professor, Department of Mechanical Engineering, E.G.S. Pillay Engineering College, Nagapattinam, Tamilnadu, India. Email: J.Jeevamalar@gmail.com.
R.Vimalraj, UG Student, Department of Mechanical Engineering, E.G.S. Pillay Engineering College, Nagapattinam, Tamilnadu. Email: vimalraj6499@gmail.com.
M.Vigneshwaran, UG Student, Department of Mechanical Engineering, E.G.S. Pillay Engineering College, Nagapattinam, Tamilnadu. vigneshwaran104@gmail.com..
G.Vignesh, UG Student, Department of Mechanical Engineering, E.G.S. Pillay Engineering College, Nagapattinam, Tamilnadu. vignesh4946@gmail.com.

[8] studied the impact of magnetic field on the nearest dry EDM process and observed that magnetic field enhances the debris flushing, re-melting and adhering of melted material to work surface decreases, TWR is improved.

Jung & Kwon [9] derived an optimum machining condition for creating a micro-hole with a maximum aspect ratio. It was proved that TWR and the entry and exit clearances have a substantial impact on the size of the micro-hole. In order to find the drilling factors influencing the TWR and the entry and exit clearances, Grey relational analysis was implemented. The supply voltage and the capacitance were identified as the most important influencing factors. Bozdana et al. [10] attempted to improve the drilling and surface properties of aerospace alloys such as Ti-6Al-4V and INC718 alloy through the fast hole r-EDM process using hollow Cu and brass tools. From the study, it was observed that the values of MRR, TWR, and SR of machined surfaces were affected by suitable selection of tool and the choice of creating through or blind hole.

Yilmaz & Okka [11] developed an intelligent and automated method for the prediction of machining performance of superalloys like Ti-6Al-4V and INC718 alloy using EDM hole drilling. The authors compared the efficiency of single and multi-channel tools during drilling of holes in Ti-6Al-4V and INC718 alloy. The single-channel tool has relatively better MRR and less TWR than multi-channel tools. Manohar et al. [12] made an empirical analysis to evaluate the influence of Electrode bottom profiles while drilling INC718 alloy. From the experimental outcomes, it was discovered that the bottom surface profile of the electrode was contributing towards a few parameters like MRR, TWR, SR and Surface Integrity (SI).

Lin et al. [13] presented a study to assess the machinability of the INC718 alloy by Grey-Taguchi technique. The effects of I_p, T_{on}, T_{off} and discharge distance on TWR, MRR and IEG of INC718 alloy were studied. The optimization of input factors of the INC718 alloy was carried out to realize low TWR, high MRR and, low IEG. Deshmukh et al. [14] carried out an empirical analysis of EDD of holes on INC718 alloy using brass electrode. The impact of machining factors such as I_p, T_{on}, T_{off} and, capacitance on MRR and TWR were calculated and the results revealed that the proposed method can realize consistent extrapolation of results within suitable accuracy. Rajesha et al. [15] presented an optimization model for machining the INC718 alloy with a hollow electrode. The optimized results revealed that the hollow tool produced better machining characteristics with low TWR. It is realized that while processing the same size of the INC718 alloys with a solid electrode, it consumes about 40% more machining time than that consumed by a tubular electrode. It also aids in reducing the degradation of the insulating fluid.

Jeevamalar et al. [16] investigated the optimization of machining factors of EDM while machining INC718 alloy. A CCD based RSM was employed to study the relational measure of parameters such as MRR and SR through I_p, T_{on} and T_{off} for machining of INC718 alloy using hollow Cu tools. Unune & Mali [17] studied the impact of nature of different electrodes like Cu, Cu-W and W electrodes on MRR and TWR of micro-EDM drilling in the INC718 alloy. The numerical results from the experiments revealed that the Cu tools provide in maximum MRR at all values of IEG voltage and capacitance followed by Cu-W and W tools. Bharti et al. [18] examined the input parameters of the INC718 alloy during machining with the Copper tool. I_p and T_{on} were observed as the most significant factors for MRR, SR and, TWR. Additionally, the duty cycle (τ) and tool lift time were signified as the least significant factors.

Ahmad & Lajis [19] carried out the experiments to find the optimum solution corresponding to I_p.,T_{on} and powder concentration. These factors have an important effect on the smoothness of machining of the INC718 alloy. The numerical results for MRR, TWR and, SR are analyzed after EDM machining of INC718 alloy using Copper tools. Kanekar & Meshram [20] examined and optimized the performance metrics to select optimal tool material having greater MRR, better surface quality and lower TWR. For four electrodes of various materials (Gr, Cu, Br and, Al) are industrialized by three different fabricating methods, namely Vertical Milling Machine, Net Shape Casting and Die Sinking EDM. Two cutting-edge techniques viz. SAW and TOPSIS are implemented to investigate the measures of machining performance and to forecast the most favorable choice of each electrode.

Yilmaz & Okka [21] presented a comparative experimental study of EDM fast hole drilling of INC718 alloy and Ti-6Al-4V workpieces by means of single and multi-channel tubular electrodes prepared of brass and Cu materials. The experimental results exhibited that the single-channel tool has relatively better MMR and lower TWR and multi-channel tools yield better surfaces than single-channel tools for both alloys. Furthermore, they demonstrated that Cu tools endure lower TWR than brass for both types of tools. Jeswani [22] explored the effects of addition of Gr-powder to kerosene. The author stated that the MRR was improved by 60% and TWR was reduced around 15% using the kerosene with 4 g/l Gr-powder concentration.

Luis et al. [23] used the second order models to study the effect of input factors on performance measures (i.e., MRR and TWR). On account of MRR, the main significant parameters for a confidence level of 95% were generator intensity and V_g. TWR was in decreasing order of significance due to the most noteworthy parameters, for example, intensity, T_{on} and flushing pressure.

The literature survey reveals that the no significant works have been done yet during Tungsten Powder Mixed Electrical Discharge Drilling on Inconel 718 superalloy**.** The aim of this research work is to find the influence and effects of input parameters during EDM drilling on Inconel 718 when Tungsten powder is mixed into Kerosene dielectric fluid to minimize the Tool Wear Rate.

II. MATERIALS AND METHOD

In this present work, 25mm diameter of Inconel 718 rod is selected as a workpiece material and single channel hollow copper electrode, the size of 12x9mm diameter is selected as a tool. Die sinking EDM (ELEKTRA-M100 MODEL) machine is used to perform the trials. A separate tank is attached to the EDM machine and the kerosene dielectric fluid is mixed with tungsten powder with a concentration of 4g/ltr and is shown in fig. 1.

Fig. 1.Experimental Setup of W-PMEDD

From the literature review, it is observed that I_p, T_{on}, and T_{off} has a significant influence on tool wear Rate. I_p, T_{on}, and T_{off} were selected to study the influences of individual and combined effect of input parameters, and is shown in table I.

Table- I: Process Parameters and their levels

Factor No.	Factors	Levels		
		1	*2*	*3*
1	Peak Current (Amp)	10	12.5	15
2	Pulse-on-time (µs)	500	1000	1500
3	Pulse-off-time (µs)	200	500	800

Response Surface Methodology (RSM) approach is the method for making a decision the relationship between different input process parameters with the different machining performances and researching the effect of these process parameters on the coupled responses. The relevant process parameter selected for the present investigation is I_p, T_{on} and T_{off} on the TWR during the W-powder mixed EDD process. For the three variables, the design is required 20 trials with 8 factorial points, 6 axial points to frame face-centered composite design with α=1 and 6 center points for reproduction to examine the experimental error. The design is generated and analyzed using MINITAB 18.0 statistical package. The experiment has been carried out by central composite second order rotatable design.

Tool Wear Rate is selected as the output response. The measure of TWR is estimated by calculating the difference in weights before and after each machining using an electric balance with an accuracy of 0.001mg and is put into a table II.

Table – II: Experimental Run order and Results

Trial No.	I_p (Amps)	T_{on} (µs)	T_{off} (µs)	TWR (g/min.)
1	10	500	200	0.240
2	15	500	200	0.354
3	10	1500	200	0.212
4	15	1500	200	0.224
5	10	500	800	0.168
6	15	500	800	0.249
7	10	1500	800	0.198
8	15	1500	800	0.186
9	10	1000	500	0.219
10	15	1000	500	0.286
11	10	1000	800	0.220
12	12.5	500	200	0.236
13	12.5	1000	200	0.244
14	12.5	1500	200	0.219
15	12.5	500	500	0.035
16	12.5	1000	500	0.183
17	12.5	1500	500	0.211
18	12.5	500	800	0.192
19	12.5	1000	800	0.394
20	12.5	1500	800	0.381

III. RESULTS

The relationship between the input factors and the calculation of output performance is based on the Response Surface Method. Using the experimental results a mathematical model based on the second order polynomial equation (1) is developed for TWR is as follows:

$$\begin{aligned} TWR &= 0.112 - 0.0965 * Ip + 0.001113 * Ton \\ &+ 0.000210 * Toff + 0.00638 * Ip * Ip \\ &+ 0.000060 * Ip * Ton - 0.000001 * Ip * Toff \qquad (1) \end{aligned}$$

ANOVA for Tool Wear Rate is shown in table III.

Table – III: Analysis of variance for Tool Wear Rate

Source	DF	Adj. SS	Adj. MS	F-Value	P-Value
Model	9	0.1165	0.0130	71.94	0.000
Linear	3	0.0340	0.0114	63.14	0.000
I_p	1	0.0002	0.0003	1.39	0.265
T_{on}	1	0.0133	0.0133	74.14	0.000
T_{off}	1	0.0205	0.0205	113.89	0.000
Square	3	0.0140	0.0047	25.81	0.000
I_p*I_p	1	0.0043	0.0044	24.28	0.001
$T_{on}*T_{on}$	1	0.0005	0.0005	2.71	0.131
$T_{off}*T_{off}$	1	0.0021	0.0021	11.81	0.006
2-Way Inter.	3	0.0685	0.0228	126.86	0.000
I_p*T_{on}	1	0.0457	0.0457	254.04	0.000
I_p*T_{off}	1	0.0000	0.0000	0.03	0.878
$T_{on}*T_{off}$	1	0.0228	0.0228	126.51	0.000
Error	10	0.0018	0.0001	*	*
Lack-of-Fit	5	0.0008	0.0002	0.73	0.633
Pure Error	5	0.0010	0.0002	*	*
Total	19	0.1183	*	*	*

IV. DISCUSSION

A. Influence of Peak Current and Pulse on time on TWR

The on-time interaction of current and pulse on TWR is exposed in fig. 2. It can be expected that with the rise in on-time pulses and current values, TWR will increase relative. As the current increases to 12A the TWR decreases but the discharge current in the 12A to 15A range rises further. The TWR increases with peak current due to the higher discharge energy, and because of this higher discharge energy the geometry of the tool geometry rapidly as the heat energy is intended in a very small portion.

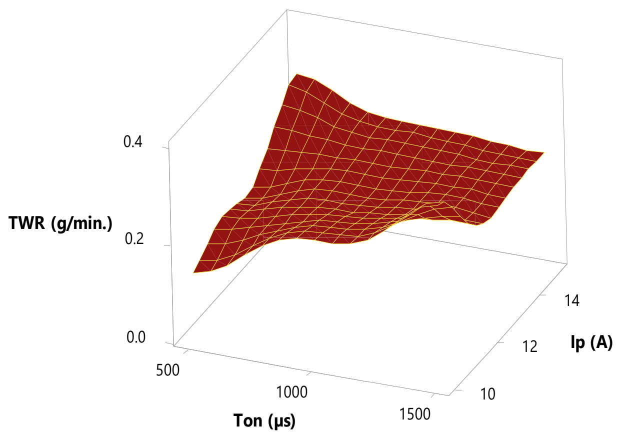

Fig. 2.Influence of I_p and T_{on} on TWR

From the figure, TWR is observed to decrease on time, with corresponding pulse rise. This could be due to the fact that high heat energy is produced at the workpiece and electrode interface at a high pulse on values.

Due high heat energy, the volume of the molten material at tool-workpiece interface increases, which need appropriate flushing. However as the level of pulse off time is too small so suitable flushing does not occur which results in the decrease in TWR. On the other hand, the TWR is decreased when the 4g/ltr concentration of Tungsten powder additive with the combination of high peak current and longer pulse duration.

B. Influence of Peak Current and Pulse off time on TWR

The influences of the current and pulse off-time on TWR are shown in fig. 3. It can be concluded that TWR proportionally increases with an increase in pulse off time and peak current values. When increasing the discharge current, the TWR is also increasing. Due to the increase in current, spark energy increases at higher current values due to the expansion of the plasma channel in the discharge gap. When increasing the pulse off time to 500µs the TWR is also decreasing, but further TWR is increasing with an increase of pulse off time. It is because an increase in the pulse off time, the inter-electrode distance becomes smaller. This, in turn, causes a reduction of the electric resistance of the electrolyte and increases the current density and then TWR.

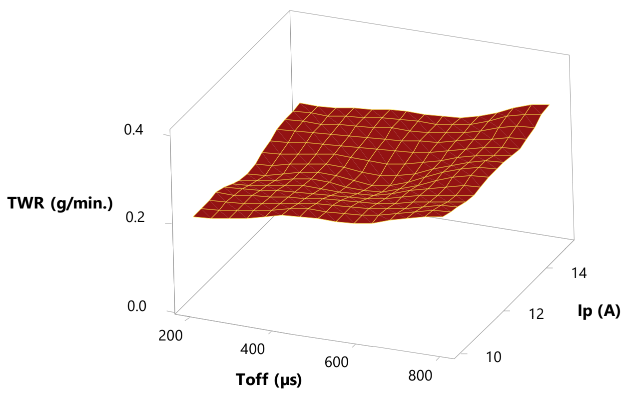

Fig. 3.Influence of I_p and T_{off} on TWR

C. Influence of Pulse on time and Pulse off time on TWR

Fig. 4 shows that with the on-time rise in pulse, TWR is reduced. This may be due to reason that at a high value of pulse on time, high heat energy is generated at the electrode and workpiece interface. Because of the high heat energy, the volume of the molten material at tool-workpiece interface increases, which need appropriate flushing.

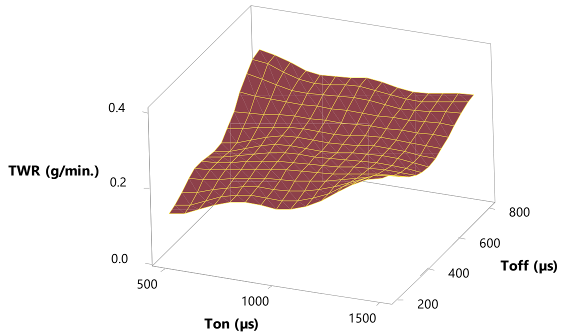

Fig. 4.Influence of Ton and Toff on TWR

When increasing the pulse off time to 500µs the TWR is also decreasing, but further TWR is increasing with an increase of pulse off time. It is because an increase in the pulse off time, the inter-electrode distance becomes smaller. This, in turn, causes a reduction of the electric resistance of the electrolyte and increases the current density and then TWR.

V. CONCLUSION

Inconel 718 was machined by Electrical Discharge Drilling and Tungsten particle was suspended into kerosene dielectric and a lower TWR has been achieved. Mathematical modeling with the help of CCD based RSM method has lead to the following conclusions about the variation of response parameters in terms of independent parameters within the specified range. From the analysis, the following conclusions are drawn:

1) When 4 g/ltr of W-powder is added the TWR ranges from 0.035g/min to 0.394g/min.
2) TWR increases with an increase in peak current but decreased gradually with the increase of the pulse-on time. The lowest TWR with value - 0.035g/min was achieved at 12.5A of peak current 500µs of pulse on time and 500µs pulse off time, respectively.
3) The empirical relationship was developed by ANOVA for Tool Wear Rate on W-powder mixed EDD in kerosene dielectric fluid.
4) I_p*T_{on} (38.64%) was the most influential parameter, followed by T_{on}*T_{off} (19.24%) and T_{off} (17.32%) on TWR.
5) Surface plots were drawn and used to find the individual and interactive effects of input parameters.
6) From the graphs, individual effects of T_{on} and T_{off}, the quadratic effect of T_{off}* T_{off}, I_p*I_p and interactive effects of I_p & T_{off}, T_{on} & T_{off} are the most significantly affecting input parameters.
7) But the individual effect of I_p, the quadratic effect of T_{on}*T_{on} and interactive effects of the quadratic effect of I_p*T_{off} are not much significant when Tungsten powder is added into kerosene dielectric fluid.
8) The outcome of the present work will be considerable support to the industries for the improvement of the quality of Inconel 718 superalloy using W-PEDD.

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AUTHORS PROFILE

Dr. J. Jeevamalar is working as an Associate Professor in the Department of Mechanical Engineering at E.G.S. Pillay Engineering College, Nagapattinam.
Fields of scientific research: Finite Element Analysis, EDM Machining and optimization.
Scientific activity: Having 12 international publications and participated in 15 International/National conferences. Author has 18 years of experience in both teaching and industry.

R. Vimalraj pursuing Final year B.E. in the Department of Mechanical Engineering at E.G.S. Pillay Engineering College, Nagapattinam. His area of interest is Design and Manufacturing Technology.

M. Vigneshwaran pursuing Final year B.E. in the Department of Mechanical Engineering at E.G.S. Pillay Engineering College, Nagapattinam. His area of interest is unconventional machining processes.

G. Vignesh pursuing Final year B.E. in the Department of Mechanical Engineering at E.G.S. Pillay Engineering College, Nagapattinam. His area of interest is Design and Thermal Engineering.