Perform the Powder-Mixed Electrical Discharge Machining of Tungsten Carbide Alloy for Analysis of Machining Characteristics

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ABSTRACT

In this paper, the powder-mixed electrical discharge machining of tungsten carbide has been performed by using graphite and alumina powder mixed in working fluid using Taguchi approach. The Taguchi method is used to formulate the experimental layout, to analyze the effect of each parameter on the machining characteristics, and to predict the optimal choice for each EDM parameter such as pulse-on time, pulse-off time, current and powder. It is found that these parameters have a significant effect on response characteristic such as metal removal rate and tool wear rate. The signal-to-noise ratio for the response characteristics has also been calculated to perform detail investigation. Response tables (mean and S/N ratio) are used to optimize the process parameters. Further, analysis of variance (ANOVA) has been performed to show the significance and percentage contribution of each factor into the study.

Keywords: Powders, Alloy, Taguchi, S/N ratio, Discharge.

1. INTRODUCTION

Electric discharge machining popularly known as EDM, a non-traditional machining process in which the material removal takes place by a succession of electrical discharges, which occur between the electrode and the workpiece immersed in a dielectric. A spark is produced at the point of smallest inter-electrode gap, generating temperature in the range of 8,000˚C– 12,000˚C, causing erosion and vaporization of material. Owing its ability to machine HSTR (high strength temperature resistant) alloys and hard materials, produce geometrically complex shapes, the process is most widely used in mould and die making industry and in manufacturing automotive, aerospace and surgical components. However, its low machining efficiency and poor surface finish restricted its further industrial applications [1, 2]. Because of complex and stochastic nature of EDM, numerous studies have been undertaken by various researchers to establish control over machining parameters which results in better machining performance [3].

Therefore, the extension of electrical discharge machining process has been developed called powder mixed electrical discharge machining (PM-EDM) process has been used to overcome some of the limitations of conventional EDM [4, 5]. In PM-EDM, the material in powder form is mixed into the dielectric fluid in separately build tank. The powder improves the break down characteristics of the dielectric fluid, i.e. the insulating strength of the dielectric fluid decreases and consequently, the spark gap distance between the electrode and workpiece increases which makes the flushing of debris uniform. As a result, the process becomes more stable thereby improving machining rate and surface finish. Moreover, the surface produced by PM-EDM has high resistance to corrosion and abrasion [6, 7]. According to various researchers [1, 4 , 7], powder-mixed EDM process noticed successfully helps to improve the machining characteristics and various surface characteristics. The principle of PM-EDM process is shown in Figure1.

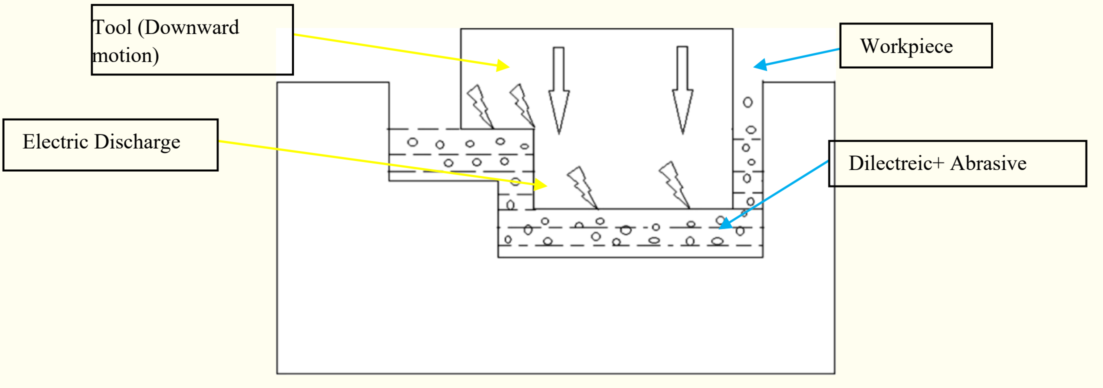

Figure 1 Principle of Powder mixed EDM

2. LITERATURESURVEY

In past, Lee and Li, (2001) observed the performance of various input parameters for EDM of WC. They showed that high pulse duration and current responsible for high MRR and surface roughness of WC. Whereas, Mahdavinejad and Mahdavinejad [8] studied the machining properties for different grades of WC by using EDM and concluded that there is a problem of instability of process during the machining of WC. Lin et al. [9] performed the EDM of Tungsten carbide by using the pulse-on time, current, duty factor and workpieces as input variables and observed the output responses MRR, EWR and SR. Kanagarajan, et al. [10] investigated the four processing parameters: pulse-on time, electrode rotation, current and flushing pressure of EDM were chosen as variables for studying MRR and SR. As per results, pulse-on time and current are the most influencing process parameters which affect machining of WC. Kung, et al. [11] used response surface methodology to optimize the process parameters for WC with PM-EDM process and concluded that aluminum powder mixed in dielectric fluid helps to increase the efficiency of the EDM process. Assarzadeh and Ghoreishi [12] worked on the multi- objective optimization of WC by considering current, gap voltage, duty cycle and pulse-on time as the input variables and central composite design as methodology.

Powders such as graphite (Gr), silicon (Si) and aluminium (Al) mixed inside the dielectric fluid were seem to produced very high surface finish corresponds to high MRR [13, 14]. Jeswani [15] used C abrasive in dielectric fluid and shows that MRR should be increased as 60% and TWR reduced as 15%. In another study, authors concluded that with addition of Si or Gr abrasive with particle size below 15 µm and a low abrasive concentration (range 2-15 g/l) is enough to get the low surface roughness i.e. 1.8 and 2.0 µm [16].

3. EXPERIMENTALDETAILS

In PM-EDM process, powders are mixed into the dielectric fluid in the tank and to avoid the powder to get mixed into the filtering system, a transparent bath like container (10 liters capacity), called machining tank is placed in the work tank of EDM and the machining is performed in this container (as shown in Figure 2, schematic diagram of PM-EDM).

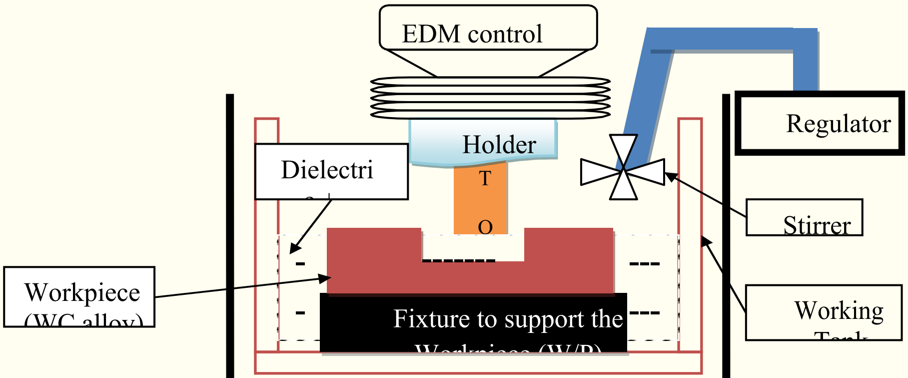

Figure 2 Schematic diagram of powder mixed electrical discharge machining process setup.

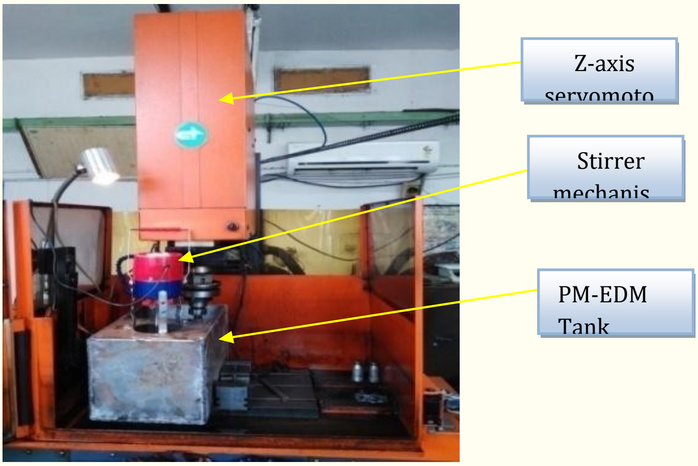

Figure 3 Experimental setup (Model no. T-3822).

For better circulation of the powder mixed in the dielectric, a stirrer is also used to shake the powder continuously in the box whose rpm is controlled by a heavy duty regulator. Experimental work has been performed on CNC EDM spark erosion Charmilles Technologies (Model no. ROBOFOR M20) as shown in Figure 1. Tungsten carbide with composition, W-65.50%, Ti-15.47%, Co-10.07%, Nb-4.69% and Cu-3.66%, is used as workpiece material. Electrolytic copper is used as tool and EDM oil is used as working fluid.

3.1 Setting of the process parameters and theirlevels

To study the response characteristics i.e. material removal rate (MRR) and tool wear rate (TWR) of PM-EDM process, four input parameters used are (i) pulse-on, (ii) pulse-off, (iii) current and (iv) powder. The various parameters and their levels are mentioned in Table 1.

Table 1 Varying and Fixed factors with settings/levels.

Sl. no.	Machining parameters	Units	Symbol	Levels		
				Level-1	Level-2	Level-3
Varying input parameters						
1.	Pulse-on time	μs	A	15	50	100
2.	Pulse-off time	μs	B	10	50	75
3.	Current	A	C	3	6	9
4.	Powders	-	D	graphite	alumina	-
Fixed input parameters						
1.	Open circuit voltage	V	135 ± 5%			
2.	Polarity	(+/-)	Positive			
3.	Tool	-	Copper			
4.	Machining time	Min	10			
5.	Powder concentration	g/l	15			

There are four factors with three levels which have been finalized on the basis of pilot experimentation and literature survey. The number of factors and their levels determine the total degree of freedom (DOF) for the experiment. As degree of freedom for each factor is given by K-1, where K is the number of level for each response, therefore the total degree of freedom is 8; so according to Ross [13], OA L_{27} is capable to handle these factors. Table 2 shows the L_{27} OA experimental design used in the study; it also shows the values of MRR and TWR values obtained for all the 27 experiments with signal-to-noise ratio for eachexperiment

Table 2 Taguchi L_{27}OExperimental design and output values.

Sl. no.	Pulse-on Time, (µs)	Pulse-off Time, (µs)	Current, (A)	Powder	MRR, (mm^3/min)	MRR, (S/N ratio)	TWR, (mm^3/min)	TWR, (S/N ratio)
1	15	10	3	C	1.569	3.9125	0.674	3.42680
2	15	10	6	Al_2O_3	2.201	7.8293	0.769	2.95040
3	15	10	9	-	2.422	4.4647	0.898	1.13011
4	15	50	3	Al_2O_3	14.882	6.0855	1.036	0.14010
5	15	50	6	-	11.406	7.3135	1.039	3.19788
6	15	50	9	C	9.637	12.4691	0.531	2.05846
7	15	75	3	-	1.472	1.7556	1.446	-1.23659
8	15	75	6	C	1.138	1.0308	1.932	-3.05799
9	15	75	9	Al_2O_3	1.841	14.8733	0.836	5.54732
10	50	10	3	C	2.168	1.1228	0.774	8.06806
11	50	10	6	-	9.481	7.8081	0.928	-1.92429
12	50	10	9	Al_2O_3	6.819	16.7631	0.485	6.28517
13	50	50	3	C	1.463	19.9608	1.132	-5.23002
14	50	50	6	-	2.623	17.4092	0.949	-0.92210
15	50	50	9	C	5.662	19.5928	1.269	-0.34901
16	50	75	3	-	2.119	9.9524	0.882	3.76850
17	50	75	6	C	8.231	18.3091	0.688	3.24823
18	50	75	9	Al_2O_3	8.102	15.7094	0.861	1.29994
19	100	10	3	C	8.462	17.9349	0.989	2.03647
20	100	10	6	Al_2O_3	5.741	21.0200	0.640	1.29994
21	100	10	9	-	5.542	20.9158	0.528	-0.89863
22	100	50	3	Al_2O_3	10.229	16.4747	0.936	4.12419
23	100	50	6	-	9.954	21.1579	1.826	1.29994
24	100	50	9	C	6.754	21.9319	1.421	-0.30720
25	100	75	3	-	11.465	15.7094	0.763	5.54732
26	100	75	6	Al_2O_3	11.943	19.7747	1.064	-1.02151
27	100	75	9	C	12.246	20.6540	1.237	0.50056

3.2 Machining Performance Measurement

To evaluate the PM-EDM machining performance, the MRR or TWR is estimated after the each run by calculating the difference between the initial weight and the final weight of the sample in specified set of conditions as shown in Eq. (1):

$$MRR = Wi - Wf / p \times t$$

W_i= Initial weight of sample, W_f= Final weight of sample, t = Time period of trials, ρ = Density of sample. MRR and TWR are measured using a weighing machine with least count as 0.001 gm.

4. RESULTS ANDDISCUSSIONS

In this chapter, the data of MRR and TWR obtained from 27 experiments are analyzed by using mean and S/N ratio graphs followed by response tables. At last, ANOVA analysis for mean was performed to show the significant factors and their contributions in the study.

4.1 Result and discussion for material removalrate

In order to see the effect of process parameters on the material removal rate, experiments were conducted using L27 OA. The experimental data is given in Tables 2.The average values of material removal rate for each parameter at levels 1, 2 and 3 for raw data and S/N data are plotted in Figures 3a and b respectively.

Figures 4a and 4b shows that the MRR increases with increase in pulse-on time and current, whereas it initially increases with increase in pulse-off time and then decreases suddenly. With increase in input discharge energies (pulse-on time and current), the temperature between both the electrodes increases, which helps to melt and evaporate huge amount of material out from the electrodes; hence increases MRR. With addition of graphite and alumina powder MRR increases as compared to simple EDM process, graphite seems to be most effective to improve material removal rate for PM-EDM of WC. The interactions effect found insignificant for this study, therefore interaction effect get ignored.

Response table for raw data (mean) and S/N ratio for MRR are shown in Table 3a and b. MRR is higher-the-better response characteristic, hence higher value has been selected from the response tables. According to response tables, pulse-on time is the most effective process parameter followed by current, pulse-off time and powder. The most significant values are highlighted by star (*) in response table. Residual plot is used to evaluate the data for the problems like non normality, non-random variation, non-constant variance, higher-order relationships, and outliers. It can be seen from Figures 5 that the residuals follow an approximately straight line in normal probability plot and approximate symmetric nature of histogram indicates that the residuals are normally distributed. Residuals possess constant variance as they are scattered

randomly around zero in residuals versus the fitted values. Since residuals exhibit no clear pattern, there is no error due to time or data collection order. ANOVA analysis for MRR is shown in Table 4 below. It concludes that pulse-on time (57.31%) found most contributing for MRR followed by the current (11.12%) and powder (10.19%). Rest, al the terms are found insignificant for the MRR

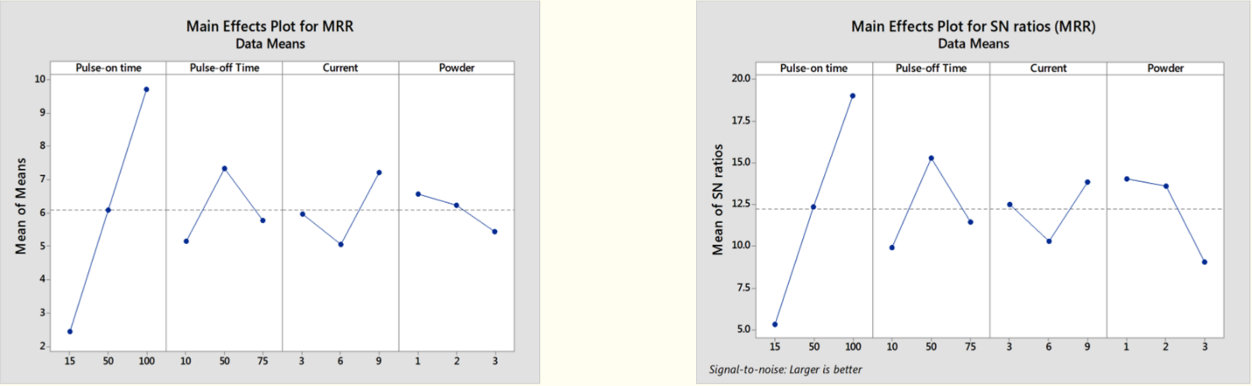

Figure 4 Effect of process parameters upon material removal rate

Table 3 Response table for (a) mean of raw data of MRR, (b) S/N ratio of MRR

Level	Pulse-on Time, A	Pulse-off Time, B	Current, C	Powder, D
1	2.259	5.259	5.911	6.358*
2	6.098	7.337*	5.171	6.134
3	9.717*	5.878	7.393*	5.201
Delta	7.458*	2.079	2.222	1.157
Rank	1	3	2	4
(b) Response table for S/N ratio of MRR				
Level	**Pulse-on Time, A**	**Pulse-off Time, B**	**Current, C**	**Powder, D**
1	5.137	10.008	12.612	12.612*
2	12.510	15.012*	10.008	13.209
3	18.506*	11.785	15.116*	9.987
Delta	13.369*	5.004	5.108	4.504
Rank	1	3	2	4

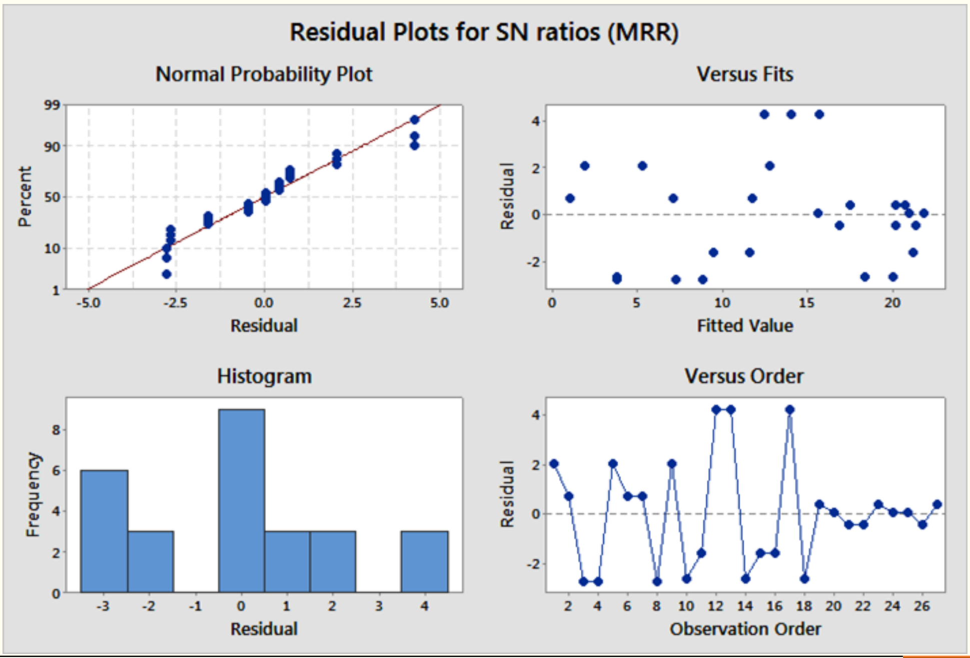

Figure 5 Residual Plots for MRR based on S/N for 27 performed experiments.

Table 4ANOVA for mean (raw data) of material removal rate

Factors	DF	SS	MS	F	% of contribution	Status
Pulse-on Time, A	2	237.018	118.50	25.34	57.31	√
Pulse-off Time, B	2	22.686	11.343	2.43	5.48	×
Current, C	2	45.997	22.998	4.92	11.12	√
Powder, D	2	42.147	20.073	4.10	10.19	√
P-on Time × P-off Time	4	27.330	6.832	1.46	6.60	×
P-on Time × Current	4	10.617	2.654	0.57	2.56	×
P-on Time × Powder	4	2.661	0.665	0.14	0.64	×
Residual error	18	28.060	4.677		6.78	
Total	26	413.516			100	
S= 2.863, R-Sq=92.5%, R-Sq(adj) =78.7%						

Here in both *F-critical selected is 3.55, here √ represents a significant term and × represents the insignificant terms

4.2 Result and discussion for tool wearrate

The experiments performed (shown in Table 2) provide the TWR value for all the 27 experiments. The average values of tool wear rate for each parameter at levels 1, 2 and 3 for raw data and S/N data are plotted in Figures 4a and b respectively.

Figures 6a and b shows that the tool wear rate increases with increase in current, whereas, it shows increasing trend initially for pulse-on time and then sudden decrease at high pulse-on time. Middle value of pulse-off time shows high TWR, lowest p-off time gives low TWR value; which is required. Alumina powder gives low TWR as compared to simple EDM and C powder. C powder shows high TWR because with addition of graphite powder, the material removal rate increases which ultimately also increases the TWR. Hence, for low TWR alumina powder is found suitable from the results. Residual plot is used to evaluate the data for the problems like non normality, non-random variation, non-constant variance, higher-order relationships, and outliers. It can be seen from residual plot do not show any problem in the distribution of the data and model assumptions (Figures7).

TWR is lower-the-better response characteristic; hence the lower value has been selected from the response table. Response table (Table 5a and b) shows that current is the most influencing parameter for TWR followed by pulse-off time, powder and pulse-on time. The significant values are highlighted by star in response table.

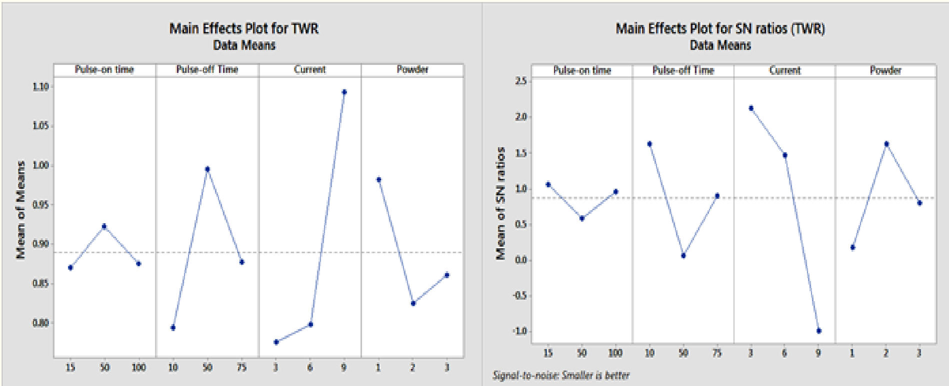

Figure 6 Effect of process parameters upon mean of tool wear rate.

Table 5 Response table for (a) mean of raw data of TWR, (b) S/N ratio of TWR

(a) Response table for mean of raw data of TWR				
Level	**Pulse-on Time, A**	**Pulse-off Time, B**	**Current, C**	**Powder, D**
1	0.8702*	0.7948*	0.7756*	0.9822
2	0.9227	0.9959	0.7989	0.8248*
3	0.8752	0.8774	1.0937	0.8611
Delta	0.0524	0.2011	0.3181*	0.1574
Rank	4	2	1	3
(b) Response table for S/N ratio of TWR				
Level	**Pulse-on Time, A**	**Pulse-off Time, B**	**Current, C**	**Powder, D**
1	1.05652	1.62860	-0.98474*	1.62538
2	0.58603*	0.06785*	1.46399	0.17960*
3	0.95892	0.90502	2.12223	0.79649
Delta	0.47049	1.56075	3.10697*	1.44578
Rank	4	2	1	3

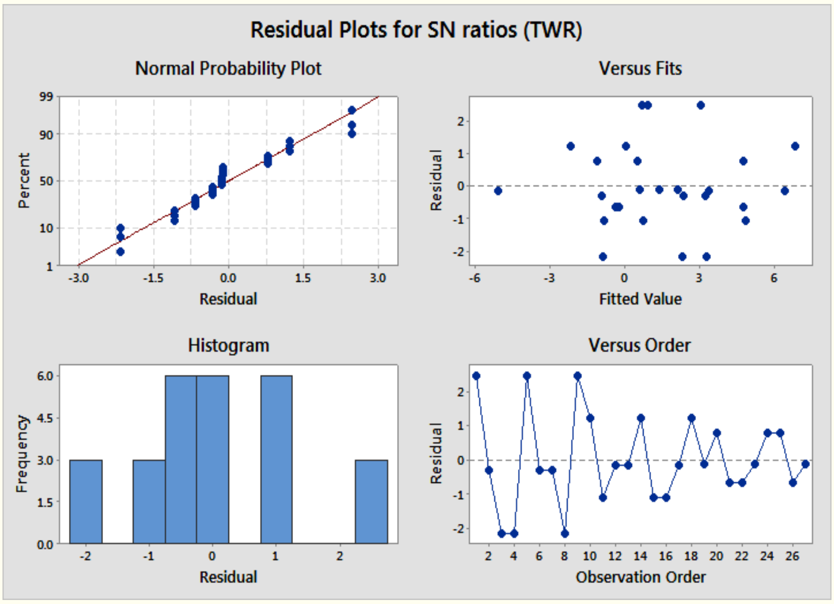

Figure 7 Residual Plots for TWR based on S/N for 27 performed experiments.

ANOVA analysis for TWR is performed at 95% confidence interval, represented in Table 6. It shows the current is the most contributing factor (24.71%), followed by pulse-off time (19.30%) and powder (19.08%). Rests of the factors are found insignificant for the study.

Table 6 ANOVA for mean (raw data) of tool wear rate

Factors	DF	SS	MS	F	% of contribution	Status
Pulse-on Time, A	2	0.5839	0.18663	2.57	15.09	×
Pulse-off Time, B	2	0.7465	0.34196	3.96	19.30	√
Current, C	2	0.9557	0.64285	6.59	24.71	√
Powder, D	2	0.7382	0.49205	4.37	19.08	√
P-on Time × P-off Time	4	0.07000	0.035002	0.48	1.81	×
P-on Time × Current	4	0.32275	0.080689	1.11	8.34	×
P-on Time × Powder	4	0.01508	0.007542	0.10	0.38	×
Residual error	18	0.43497	0.072494		11.24	
Total	26	3.86722			100	
S= 1.163, R-Sq=82.9%, R-Sq (adj) =79.6%						

Here in both *F-critical selected is 3.55, here √ represents a significant term and × represents the insignificant terms

4. CONCLUSION

This study investigates the performance characteristics for PM-EDM of WC alloy. As evident from literature survey that WC alloy is a unique and very DTM material with vast applications in industry. Therefore, Taguchi method has been used to determine the main effects, significant factors and optimum machining condition to the performance of EDM. Graphite and alumina powders are used in working fluid for machining of WC alloy. Results from this work are concludedas;

1. For material removalrate;
   - ForhighMRR;author'sfoundthathighpulse-ontime(100µs),mediumpulse-offtime(50µs),highcurrent(9A) and graphite powder are optimal parameter settings for both raw data of MRR and S/N ratio.
   - Pulse-on time comes out to be most influential process parameter for high material removalrate.
   - ANOVA analysis also validates that pulse-on time is the most contributing factor followed by current and powder. Whereas, pulse-off time found insignificant for thisstudy.
2. For tool wearrate;
   - Results found that low pulse-on time (15 µs), low pulse-off time (10 µs), low current (3 A) and alumina powder found optimal for low TWR value. Whereas, in case of S/N ratio medium pulse-on time (50 µs) and medium pulse-off time (50 µs) foundoptimal.
   - From response Table of TWR, current comes out to be most significant parameter. Whereas, in ANOVA analysis shows that current is the most influential process parameter followed by pulse-off time andpowder.

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