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Abstract- This paper depicts the experimental study of the input parameters of EDM i.e. current, pulse on time and pulse off time on output parameters material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR). The workpiece materials selected was AISI D2. The aluminium used as tool electrode and EDM oil as dielectric fluid. Taguchi, method was used to perform experiments, L_9 orthogonal array was applied using MINITAB software. Signal to Noise (S/N) ratio and ANOVA were employed for parameter optimization and to achieve max MRR, min SR and TWR. The results indicate that the most prompting factor for MRR is Pulse off time. For TWR, the most influencing factor is current. For SR, the most prompting factor is pulse on time. Optimization is done by using Taguchi method on MINITAB 17 software.

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I. Introduction

Electric Discharge Machine (EDM) is a non-traditional machining process. It has number of applications in die making, punches and molds industry. It also finds application in manufacturing of finished parts in automobile, also in manufacturing of surgical components. In EDM, electric spark is produced between workpiece and electrode and due to this spark material gets eroded from workpiece and tool electrode [1]. So this process can be successfully employed to materials which are electrically conductive. Hardness, shape, toughness and brittleness don't cause any restrictions [2]. In die sinking EDM, the shape which is to be produced on workpiece, the tool should be replica of that shape. Both tool electrode and workpiece are dipped in a dielectric fluid like EDM oil, Kerosene etc. The workpiece and electrode are placed at a very close distance and it depends on operating conditions and called as spark gap [3]. Modern era of EDM, i.e. from 1995 to till date. Many new aspects has been developed, namely micro-machining by EDM and dry EDM i.e. EDM without dielectric fluid. Now a days EDM is most acceptable technique for MRR [3]. For micro machining, ultrasonic vibration method is apt, dry machining is economical and water EDM is safe and conductive working environment, Powder mixed EDM is concerned more on improving surface quality [4]. The viability of machining Tungsten carbide ceramics by EDM with a graphite electrode using Taguchi method is studied and concluded that the current mainly effects the EWR and SR. The pulse duration is the most influencing factor for MRR [5]. For machining of tungsten carbide, graphite electrode gives the maximum MRR with comparison to copper and copper tungsten electrode [6]. The study of MRR by copper and graphite electrodes of different diameter is performed on XW42 tool steel. Copper is apt for roughing process, while graphite electrode is apt for finishing [7]. Copper, copper alloys and graphite has a problem of low wear resistance. A new composite ZrB2-Cu is developed to get an ideal combination of wear resistance, electrical and thermal conductivity. This composite demonstrates more MRR with less TWR than copper tool [8]. When manufacturing deep slots in low machinability materials, EDM may be the only method [9]. Investigation is done on SS 316L using compressed air as dielectric and copper electrode as tool [10]. MRR is primarily influenced by peak current and EWR is primarily influenced by peak current trailed by pulse on time [11]. For MRR, using copper as electrode input current & duty cycle is more dominant. Pulse on time and duty cycle for EWR, duty cycle and pressure for surface roughness [12]. EDM parameters using grey relational analysis on AISI SS (202), parameters mainly discharge current, and pulse off time and pulse on time [13].The effect of abrasive mixed dielectric on AISI D3steel is studied. At 6 g/ltr of concentration MRR is maximum. EDM (Abrasive mixed) outcomes in 58% more MRR as compared to traditional EDM [14]. Experiments were performed to determine factors effecting SR using brass, copper and aluminium as electrodes on Mild steel [15]. Aluminium yielded highest MRR followed by copper.

For present work, studies are conducted on AISI D2 steel using aluminium electrode to determine the MRR, TWR and SR and optimum values are predicted using MINITAB 17.

II. Workpiece and Electrode Material

AISI D2 steel is used mainly in die and mould making industry. Now a days dies are of very complicated shape so to achieve that kind of shape, non-conventional machining methods are employed because it cannot be achieved by conventional methods.

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Table 1: Chemical composition of AISI D2 steel

Composition of AISI D2								
C	Mn	Si	C_r	Ni	Mo	P	S	Fe
2.11%	0.3531%	0.48%	12.88%	0.1547%	0.4312%	0.0181%	0.0127%	Balance

Aluminium is silvery white, soft, non-magnetic, ductile material. Aluminium and its alloys are vital to aerospace industry. Aluminium is capable of super conductivity. Aluminium find its application in electrical transmission lines for the purpose of power transmission. Melting point of aluminium is 933.47 K and density 2.70 g/cm3, electrical conductivity 3.50×107 S/m.

Figure 1: Machined AISI D2 workpiece and aluminium electrode

III. Evaluation of Parameters

a) *Evaluation of MRR*

MRR is articulated as the ratio of the difference of weight of the work piece before and after machining to the machining time. MRR is measured in mg/min.

MRR= (Mi-Mf)/t

Whereas,

Mi = Weight of work-piece before machining i.e. initial weight

Mf = Weight of work piece after machining i.e. final weight

b) *Evaluation of TWR*

TWR is articulated as the ratio of the difference of weight of the electrode before and after Machining to the machining time.

EWR =Ei-Ef /t

Whereas,

Ei = Weight of electrode before machining.

Ef = Weight of electrode after machining.

c) *Signal to noise (S/N) ratio*

The main objective of the study is to examine the effect of aluminium as electrode on AISI D2 steel. Signal to Noise (S/N) ratio is selected as larger is better for MRR, smaller the better for SR and TWR.

S/N ratios are defined as:

Larger is better = -10 log (MSDHB)

Where MSDHB=1/r$\sum_{i}^{r} = (\frac{1}{y_i^2})$

r = the number of tests in a trial

y_i = observed value of response characteristics

For material removal rate (MRR) the S/N ratio is larger is better.

Where,

MSDHB = Mean Square deviation for higher the better response.

Smaller is better = -10 log (MSDLB)

Where,

MSDLB=1/r$\sum_{i=1}^{r} = (y_i^2)$,

r = the number of tests in a trial

yi = observed value of response characteristics

For Tool wear rate (TWR) the S/N ratio is smaller is better.

Where

MSDLB = Mean Square deviation for smaller the better response.

d) *Design of Experiments*

Experiments In present study, Taguchi method was used to design the experiments. For optimization of system, Taguchi Technique reduces the trial of experiments to get only the necessary trial of experiments so there will be no repeated trials and it's done using DOE. Three parameters viz., pulse on, current and pulse off were chosen as control parameters and apiece parameter has three levels shown in table 2. L_9 orthogonal array was used to design the experiments shown in table 3. To obtain accurate results, each experiment was performed three times and there mean value is taken for optimization.

Table 2: Parameter Selected and their levels

S. No.	Input Parameters	Level		
		1	2	3
1	Current (A)	6	8	10
2	Pulse On (Ton)	50	100	150
3	Pulse Off (Toff)	6	8	10

Table 3 showing the values of material removal rate, tool wear and Surface roughness. MRR and TWR are measured in grams. SR is measured in microns using surface roughness tester. Experiments were executed three times to get the accurate results.

Table 3: Observation Table

Serial No	Current Ip, A	Pulse on Ton, µs	Pulse off Toff, µs	Material removed			Tool Wear (grams)			Surface roughness		
				MRR1	MRR2	MRR3	TWR1	TWR2	TWR3	SR1	SR2	SR3
1	6	50	6	0.1195	0.1232	0.1211	0.0268	0.0234	0.0274	4.534	4.243	4.432
2	6	100	8	0.3411	0.3144	0.3356	0.0411	0.0489	0.0477	5.133	5.698	5.443
3	6	150	10	0.72	0.7329	0.7469	0.03	0.0392	0.0342	6.149	5.745	6.253
4	8	50	8	0.36	0.3713	0.3675	0.0769	0.0648	0.0698	4.378	4.135	4.051
5	8	100	10	1.0166	1.0087	1.021	0.06	0.0567	0.0622	7.297	7.546	7.069
6	8	150	6	0.2031	0.1967	0.2104	0.0269	0.0212	0.0287	6.488	6.143	6.376
7	10	50	10	0.7	0.6934	0.7062	0.133	0.1411	0.1369	6.045	6.316	6.431
8	10	100	6	0.5166	0.5251	0.5286	0.05	0.0478	0.0493	6.618	6.754	6.552
9	10	150	8	0.57	0.5772	0.5658	0.05	0.0478	0.0493	7.661	7.211	7.521

Table 4 shows the values of SN ratio and means values. SN ratio is calculated using formula given in section 3.3.

Table 4: Observation table

S.no	MRR		TWR		SR	
	SNRA1	MEAN1	SNRA1	MEAN1	SNRA1	MEAN1
1	-18.3271998	0.12126667	31.72510106	0.02586667	-11.0588253	3.572
2	-9.63634552	0.33036667	26.73957182	0.0459	-14.7229144	5.4463333
3	-2.69768287	0.73326667	29.20061811	0.03446667	-15.3648633	5.864
4	-8.72620694	0.36626667	23.01473492	0.0705	-11.6965016	3.8433333
5	0.13270037	1.01543333	24.48398351	0.05963333	-14.4654947	5.2876667
6	-13.8428249	0.2034	31.76799737	0.0256	-16.3816835	6.592
7	-3.10042071	0.69986667	17.263058	0.137	-13.8691362	4.9363333
8	-5.62398705	0.52343333	26.18865056	0.04903333	-16.5331788	6.7086667
9	-4.86816042	0.571	26.18865056	0.04903333	-16.5012866	6.6843333

Table 5 shows the response table values for current, pulse on and pulse off for material removal rate. Table 6 shows the values for Surface roughness and Table 7shows the corresponding values for tool wear rate.

Table 5: Response table for MRR

Response Table for MRR						
	Response table for S/N ratio			Response table for Means		
Level	Current	Pulse On	Pulse off	Current	Pulse on	Pulse off
1	-10.22	-10.051	-12.598	0.39	0.3958	0.2827
2	-7.479	-5.043	-7.744	0.5284	0.6231	0.4225
3	-4.531	-7.136	-1.888	0.5981	0.5026	0.8162
Delta	5.69	5.009	10710	0.2031	0.2273	0.5335
Rank	2	3	1	3	2	1

Table 6: Response table for SR

Response Table for SR						
	Response table for S/N ratio			Response table for Means		
Level	Current	Pulse On	Pulse off	Current	Pulse on	Pulse off
1	-13.72	-12.21	-14.66	4.961	4.117	5.624
2	-14.18	-15.24	-14.31	5.241	5.814	5.325
3	-15.63	-16.08	-14.57	6.11	6.38	5.363
Delta	1.92	3.87	0.35	1.149	2.263	0.3
Rank	2	1	3	2	1	3

Table 7: Response table for TWR

Response Table for TWR						
	Response table for S/N Ratio			Response table for Means		
Level	**Current**	**Pulse on**	**Pulse off**	**Current**	**Pulse on**	**Pulse off**
1	29.22	24	29.89	0.03541	0.07779	0.0335
2	26.42	25.8	25.31	0.05191	0.05152	0.05514
3	23.21	29.05	23.65	0.07836	0.03637	0.07703
Delta	6.01	5.05	6.24	0.04294	0.04142	0.04353
Rank	2	3	1	2	3	1

IV. Results and Discussions

Figure 4, 5, 6 shows the main effects plots for S/N ratio and Mean of means For MRR, TWR and SR respectively. Optimization is established on selecting the values from plots depending upon S/N ratio requirement. From table 5, means graph is drawn and displayed in fig 4. For S/N ratio we always take maximum value irrespective of smaller the better or larger is better. For mean of means, we select maximum values for optimization if S/N is higher the better and we take minimum value if it is smalleris better.

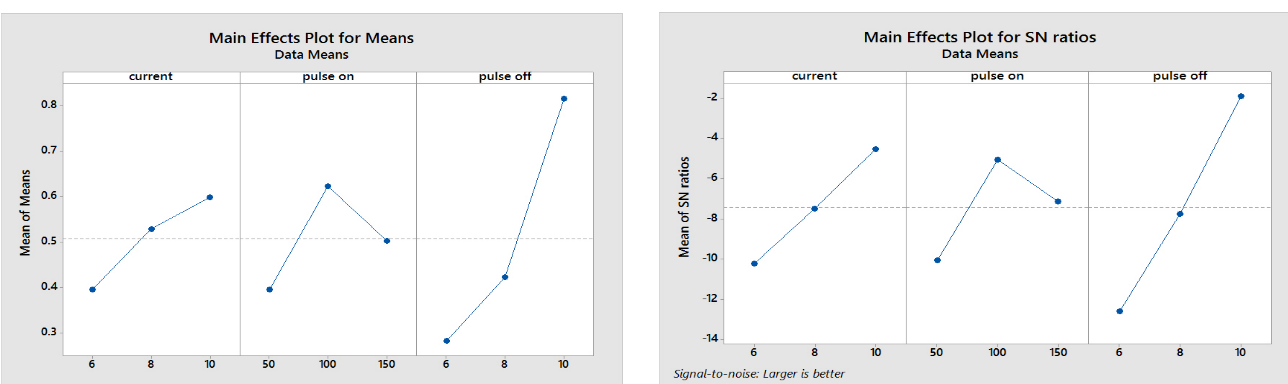

Figure 4: Mean effects plots for MRR

Graph displayed in figure 5 is made using table 7. For TWR, S/N ratio is smaller the better. So for SN ratio graph we take maximum values and for means we take minimum values for optimization.

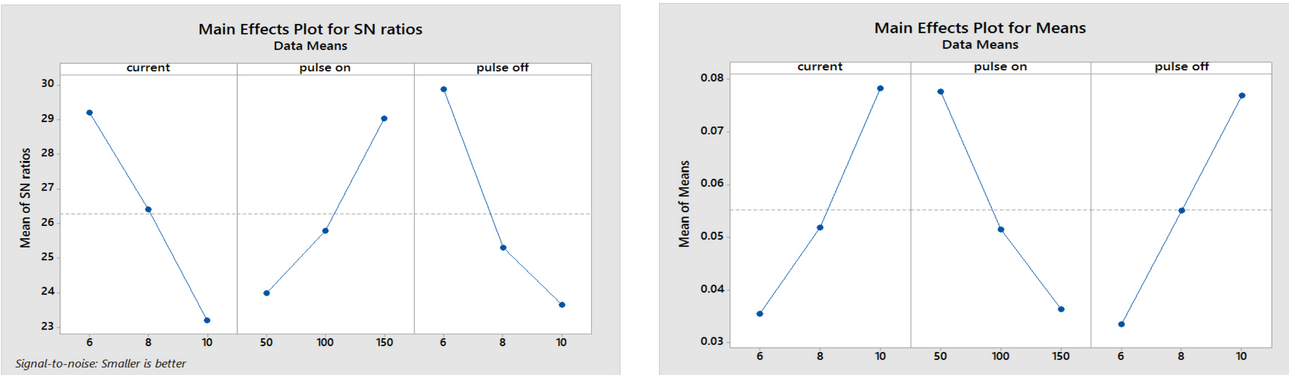

Figure 5: Mean effects plots for TWR

Graph displayed in figure 6 is made using table 6. For SR, S/N ratio is smaller the better. So for SN ratio graph we take maximum values and for means we take minimum values for optimization.

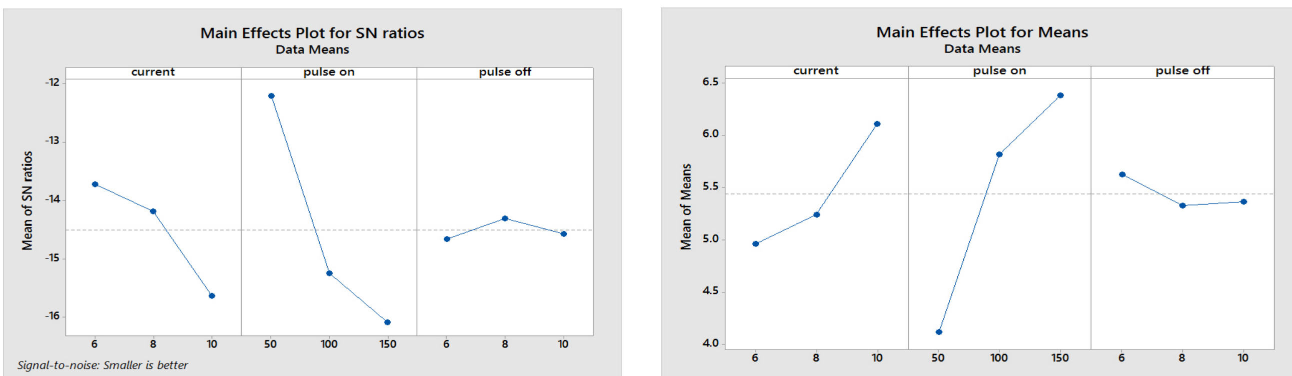

Figure 6: Mean effects plots for SR

V. Conclusion

The main motive of the present study was to experimentally inspect the effect of aluminium as electrode which is tool on MRR, TWR and SR on AISI D2 steel. Optimum conditions for the output parameters are.

1. The Optimum conditions for MRR is Current (10 A), Pulse on (100 μs), Pulse off (10 μs) for AISI D2 steel.
2. For TWR, the most prompting factor is pulse off time, followed by current and then pulse on time. The optimum condition for TWR is Current (6A), Pulse on (150 μs), Pulse off (6 μs) for AISI D2 steel.
3. For SR, pulse on time is the most prompting factor followed by current and pulse off time. The optimum condition for SR is current (6A), Pulse on (50 μs), Pulse off (8 μs) for AISI D2 steel.

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