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EXPERIMENTAL INVESTIGATION TO ASSESS THE PERFORMANCE AND OPTIMIZATION OF PROCESS PARAMETERS OF ESM ING PROCESS

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Abstract: The versatility and potential of electric spark machining (ESM) process found to be a success in present-day industries. It is competent to produce typical products that are absolute. The efficiency of electrode used in this process can be estimated with two important factors, viz., Material Erosion Rate (MER) and electrode Wear rate (EWR). The commercially available electrode materials (copper, copper alloys, silver, tungsten and graphite) should possess the characteristics like high electrical conductivity, high material removal rate, low electrode wear rate, high surface finish for the machined surface etc.) during non-contact machining of different work piece materials. With this intention, the current investigation makes an attempt to establish relations between input and output variables and also to identify the most influencing factor and its level through signal-to-noise(S/N) ratios and analysis of variance (ANOVA). The results of L9 Taguchi OA imply that MER is mostly affected by voltage gap (V_g) while using pure copper electrode and input current (Ip) in case of aluminium bronze electrode, EWR is mostly influenced by input current (I_p) while using both the electrodes, surface roughness (SR) is mostly affected by pulse on time (T_{on}) while machining with pure copper electrode and by pulse off time (T_{off}) in case of aluminium bronze electrode.

Key words: Material Erosion Rate (MER); Electrode Wear Rate (EWR); Surface Roughness (SR); Design of Experiments (DOE).

1. INTRODUCTION

Electrical spark Machining (ESM) which is a non-contact type machining process in which work piece material is eroded by means of the sparks generated between the tool and work piece in the presence of a dielectric medium. The combination of Electrode (Tool) and work piece materials is important which greatly influences the Material Removal Rate (MRR) and Electrode wear rate (EWR). Shailesh Dewangan et al., [1] optimized the characteristics of Electrical discharge machining(EDM) in the machining of AISI P20 tool steel with a graphite electrode. It is used for the zinc die casting process. Dastagiri and Hemantha Kumar [2] performed a study on the effect of EDM parameters on stainless steel& En41b work piece materials. The full factorial method for DOE and regression model is developed to predict the MER and SR. The results indicate that rise in the peak current, discharge power, increases the temperature of the work piece and hence more MRR is achieved. The crater depth & radius is affected by pulse duration for longer pulses, starts decreasing after a certain period of time, whereas MRR increases at 50% of the duty factor regardless of other machining conditions. Vikas et al. [3] found that during machining of EN-41 the input current had a larger involvement over the SR, followed by the voltage, whereas other parameters have not a significative influence. The predicted values achieved 95% confidence level and are closer to the experimental results. Shashikant et al. [4] considered Response Surface Methodology (RSM) to see the effect of various machining parameters on surface roughness while EDM in the EN19 material. EN19 is a shock absorbing material due to the presence of molybdenum and chromium in it. The results reveal that the peak current and pulse on time are the most powerful factors affecting the SR of the work piece material. It is also observed that the confirmation test done to develop the prediction model has 0.02% deviation with the experimental results. Suresh Kumar and Rajeev Kumar [5] optimized MER and EWR with the Taguchi methodology in EDM of die steel H13 materials. The S/N ratios and ANOVA disclose that current is the most dominant parameter for both MER and EWR. Sameh [6] studied the impact of spark machining parameters (MER and EWR) using surface methodology approach. During the experimentation, it is noticed that the rise of a pulse on time causes an increase in the MER slightly until it reaches a point of 200μs and then it begins to decrease. It is also observed that electrode wear ratio decrease as the pulse on time values increase for all silicon carbide percentages for a pre-set peak current and gap voltage combination. Baljinder singh et al.[7] observed the effect of spark machine parameters of H11 steel using copper. The results show that -ve polarity of the electrode is prescribed for lowering of SR. Dispersion of powder particles in a dielectric fluid enhances SR in EDM. Long peak currents yield rougher surfaces in the EDM process. Shailesh et al. [8] used the Grey-Fuzzy methodology for multi-response optimization of surface integrity attributes of EDM. The ANOVA results indicate that pulse on time is the most authoritative aspect. The predicted model developed shows an improvement and the values are closer to experimental results. Pavani et al. [9&21] used the S/N and ANOVA techniques for optimizing the input parameters in the analysis of the performance of EDM and Turning processes. The relation between input and output parameters and its influence on its performance is evaluated. Jambeswar Sahu et al. [10] used data envelopment analysis (DEA) to capture proportionate efficiency of EDM in machining of AISI D2 steel. The confirmation tests reveal that satisfactory results of response variables MRR and TWR are achieved when input current I_p is 7A and pulse on time is about 200µs. Sengottuvel et al.[11] optimized diverse aspects of EDM parameters of Inconel 718 based on Fuzzy Modeling technique. From the outcomes, it is suggested to have high current, flushing pressure & medium pulse on time. The ANOVA results show current is an utmost influence and confer in the EDM. It is also concluded that tool geometry does not influence its performance. Narender Singh et al.[12] performed Grey-relational analysis of process parameters in machining of Al–10%SiCP composites and identified that the optimal condition is obtained with current & pulse on-time at level 3 and the flushing pressure at level 1 for high MRR and low TWR. Radhika et al.[13] investigated the influence of ESM Parameters of a metal matrix composite. The S/N ratio and ANOVA calculations show that peak current was the most proeminent parameter on SR whereas MER is inversely proportional to flushing pressure because of the eradication of debris material. Parveen Goyal et al.[14] examined the surface quality of EN-31 in the presence of kerosene dielectric medium with powder metallurgy ESM electrodes. The electrodes are fabricated with different compositions of copper and manganese. The composition 70-30% has shown better results in terms of surface hardness compared to 80-20%. It is likewise contemplated that as the peak current rises, the micro hardness also raises irrespective of electrode composition. Prasanna et al., [15] worked on MER and EWR evaluation in ESM of Ti-6Al-4V using tungsten-copper electrode. The outcomes of S/N and ANOVA indicate that gap voltage has greater impact; however subject to TWR, it is gap voltage. H S Payal et al.[16] analyzed the effect of ESM parameters in machining of EN-31 in terms of SR & MER. The results of Scanning Electron & Optical Microscope reveal that the heat affected zone affects the texture of work piece and consequently reduces its life. The post machined surface shows that the molten mass is removed in the appearance of ligament, sheets and chunks. Pandey et al., [17] performed structural study of EN-31 during ESM with three different electrode materials (copper, brass and graphite). The observations made out of the study used to understand the life of the tool. Amandeep Singh and R.P Singh [18] established a relation between EDM parameters and its pursuance on MER of EN-31 Stain less material. The signal to noise ratio calculations and ANOVA exhibit that MER is highly influenced by peak current than pulse off time than pulse on time. Singaram Lakshmanan et al.[19] optimized SR using RSM. The pulse current played an important role and identified as the most influencing factor in prediction of surface roughness. Rohan Ramesh and Shrikant Tukaram [20] developed a mathematical model in the analysis of ED machining parameters on SR of EN-31 tool steel material with copper electrode using RSM. The results declare that the SR is affected by a pulse on time, voltage & duty factor. The SR decreases with an increase in gap voltage. Amoljit and Sanjeev Kumar [21] evaluated SR of EN-31, machined with Cu-Cr-Ni electrode. The percentage contribution of input parameters is determined by ANOVA. The 3.19µm surface can be generated using the method adopted for machining. The rise in micro hardness of texture is noticed because of the presence of carbides comprise of chromium. The literature mentioned above encapsulates the possible combinations of electrode and work piece materials used in ESM and finding the most dominating factor among all variables using ANOVA is given. Based on these observations, the EN-31 steel and pure copper and aluminium- bronze materials are selected as work piece and electrode for the ESM process. The objective of present work is to ESM the EN-31 steel with pure copper and Aluminium- bronze electrode materials at various combinations of input variables (gap voltage (V_g), pulse On time (T_{on}), pulse off time (T_{off}) and input current (I_p)) and analysis of output variables MER, EWR and SR using signal-to-noise ratios and analysis of variance techniques to understand the most influencing factor and its level on the performance of ESM process.

2. DESIGN OF EXPERIMENTS USING TAGUCHI METHODOLOGY

Design of experiments (DOE) starts with determining "objective" of the experimentation and selecting "Process parameters" for study. The DOE determines the plan of conducting the experiments in advance of experimentation. A well-designed set of experiments maximizes the amount of information with less effort. Often, the experiments contain a number of uncontrolled factors which are discrete. Taguchi DOE is designed and established to perform a selected number of experiments with possible combinations. The 5 steps are: outlining, screening, optimization, stability testing, and confirmation.

In this work, the Taguchi DOE designed for a particular set of experiments that determines all the properties and phenomenon of range lot set. In EDM, the input variables available are gap voltage (V_g), sensitivity (SEN), pulse on time (T_{on}), working time (T_W), pulse off time (T_{off}), polarity (+ve or -ve), surface roughness (SR). Here a total of four parameters in three levels are considered for the experimentation on Electronica make Smart ZNC 50 Electrical Discharge Machine as shown in Table1. The parameters selected are arranged as per the standard OAs available using software Minitab 17 statistical software to get the best possible combinations of selected process parameters. In the present study, L_9 OA was used and the arrangement of parameters is shown in Table 2.

Table 1. Selected levels and parameters for machining

Factors/Levels → ↓	T_{on} (µs)	T_{off} (µs)	I_p (A)	V_g (V)
1	1000	3	15	57
2	2000	6	30	64
3	3000	9	45	71

Table 2. Combination of Parameters as per L_9 OA

Exp.No	T_{on} (µs)	T_{off} (µs)	I_p (A)	V_g (V)
1	1000	3	15	57
2	1000	6	30	64
3	1000	9	45	71
4	2000	3	30	71
5	2000	6	45	57
6	2000	9	15	64
7	3000	3	45	64
8	3000	6	15	71
9	3000	9	30	57

3. MATERIALS USED FOR ELECTRIC SPARK MACHINING (ESM)

For the present study, EN 31 grade tool steel of composition C-1.5%, Mn - 0.52%, Si- 0.22%, Cr- 1.3%, S-0.05%, P- 0.05% and of dimensions 25×25 mm with rectangular cross-section as work piece material, 25mm φ ×18mm pure copper as tool material and a dielectric fluid having density at 29.5^{0}C as 0.81-0.82, kinematic viscosity at 40^{0}C as 2.4-2.5 and flash point (min) as 90^{0}C and Aluminium Bronze as electrodes are selected as shown in Fig. 1.

(a)Pure Copper Electrode

b) Aluminium-Bronze Electrode

c) Electrical Discharge Machine Used for Experimentation

Fig. 1. Electrode materials and the machine used for Electric spark machining process

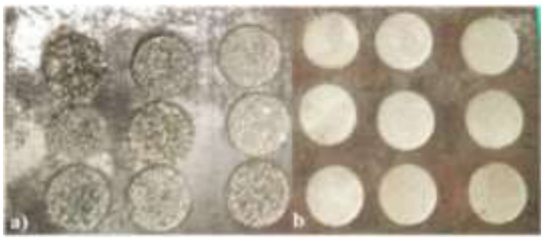


Fig. 2. Work piece after ESM using a) Pure copper and b) Al-Bronze alloy electrode materials

4. EXPERIMENTATION ON ELECTRIC SPARK MACHINE

The experimentation is done using Electronica make a smart ZNC machine (Figures 1(c) and 2) for the combination of input values shown in Table 2 and the MER and TWR calculated based on the original and final weights of the electrode and work piece specimens and are tabulated in Table 3. The surface roughness (SR) is measured for the work piece specimens using Mitutoyo SJ-201 surface roughness tester.

The MER and TWR are calculated as follows:

Material Erosion Rate (MER) and tool wear rate (TWR) = (initial weight-final weight)/(density of the material X cycle time)

Initial & final weights before and after machining are considered in mg. Density of EN31 Tool Steel, Pure copper and Aluminium-Bronze materials = 7.85g/cm^3, 8.96 g/cm^3 & 7.64 g/cm^3 . Cycle time is the amount of time taken to a machine for each impression made.

Table 3. Output Parameters measured during EDM process

Exp. No	MERx 10^{-6} (g/min)		TWR x 10^{-7} (g/min)		SR, Ra (μm)	
	Cu	Al-Bronze	Cu	Al-Bronze	Cu	Al-Bronze
1	2.14	0.67	1.87	6.88	2.53	13.01
2	2.08	1.81	1.83	0.370	3.12	14.47
3	3.50	4.24	4.69	0.013	2.94	21.64
4	4.71	1.27	6.20	0.654	5.57	14.93
5	1.98	3.18	6.95	0.981	4.05	16.23
6	1.72	2.54	1.91	0.523	3.85	17.22
7	1.64	3.18	5.76	0.013	2.93	17.93
8	1.72	1.81	1.51	0.747	3.17	14.74
9	1.76	3.18	3.16	0.065	3.34	18.53

5. ANALYSIS OF VARIANCE (ANOVA) AND CALCULATION OF S/N RATIOS

ANOVA is conducted using Minitab 17 software to interpret the level of influencing factors which is identified through S/N ratio calculations. The values tabulated in Table 3 are considered to calculate the S/N ratios. The S/N calculations are done using the following formulas for the output variables viz., MER and TWR. The goal of the present study is getting high MER and low TWR. So, to maximize the response among all the three criteria's the following larger is better for MER is considered. Whereas for TWR and SR smaller is better criteria is considered. Later the main effect plots for all input variables are drawn as depicted in Figures 3-8.

Larger is better in case of MER,

$$\text{So, } \frac{S}{N} = -10\log\left\{\sum\left(\frac{1/y^2}{n}\right)\right\} \quad (1)$$

And in the case of TWR, it should be like Smaller is

$$\text{better, so, } \frac{S}{N} = -10\log\left\{\sum\left(\frac{y^2}{n}\right)\right\} \quad (2)$$

Where n is number of observations and y is the respective characteristic. The best conditions for MER and TWR are as follows.

Table 4. S/N ratios for (MER) when EN-31 is machined with Copper Electrode

Level	(T_{on}) μs	(T_{off}) μs	(V_g) v	(I_p) Amps
1	7.960	8.141	5.835	5.373
2	8.053	5.683	5.149	4.954
3	4.678	6.868	9.708	4.323
DELTA	3.374	2.458	4.559	1.050

Table 5. S/N ratios for (MER) when EN-31 is machined with Aluminium- Bronze Electrode

Level	(T_{on}) μs	(T_{off}) μs	(V_g) v	(I_p) Amps
1	7.004	4.64	4.47	7.39
2	7.34	7.10	6.38	3.25
3	8.70	10.42	10.96	7.74
DELTA	1.69	5.78	6.49	4.49

Table 6. ANOVA results for (MER) when EN-31 is machined with pure copper Electrode.

Parame-ters	DOF	Sum Of Squares	Mean-Variance	F – Ratio	% of P	Rank
(T_{on}) ms	2	1.189	0.5946	0.490	3.89	3
(T_{off}) ms	2	12.08	6.0389	7.84	39.52	2
(V_g) V	2	17.17	8.5849	15.38	56.17	1
(I) Amps	2	0.1261	0.06303	0.05	0.412	4
Error					0.0001	
Total	8	30.5671	15.276		100	

Table 7. ANOVA results for (MER) when EN-31 is machined with Aluminium- Bronze Electrode

Parameters	DOF	Sum of Squares	Mean-Variance	F – Ratio	% of P	Rank
(T_{on}) ms	2	5.984	6.652	18.02	22.6	2
(T_{off}) ms	2	3.706	0.261	0.29	14.0	4
(V_g) V	2	12.316	1.015	1.21	46.6	1
(I) Amps	2	4.407	1.725	2.21	16.6	3
Error					0.2	
Total	8	26.407	13.202		100	

Table 8. S/N ratios for (EWR) when EN-31 is machined with Pure Copper Electrode.

Level	(T_{on}) μs	(T_{off}) μs	(V_g) v	(I_p) Amps
1	-9.221	-12.282	-5.502	-9.516
2	-12.254	-8.235	-11.396	-11.335
3	-9.606	-10.564	-14.183	-10.229
DELTA	3.032	4.047	6.681	1.819

Table 9. S/N ratios for (EWR) when EN-31 is machined with Aluminium- Bronze Electrode.

Level	(T_{on}) µs	(T_{off}) µs	(V_g) v	(I_p) Amps
1	-7.67	-8.01	-54.33	-52.84
2	-2.86	-13.98	-7.26	-6.04
3	-11.21	-4.00	-6.71	-9.42
DELTA	8.35	9.97	47.61	46.8

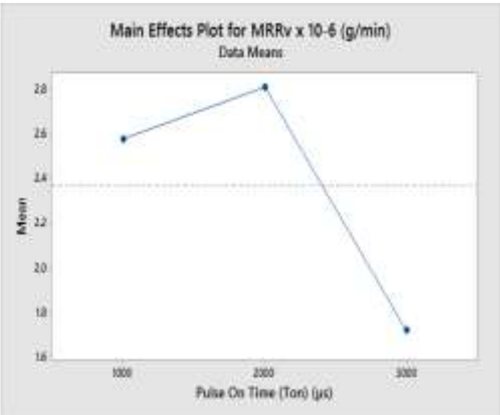
Table 10. ANOVA results for (EWR) when EN-31 is machined with Pure Copper Electrode

Parameters	DOF	Sum Of Squares	Mean-Variance	F – Ratio	% of P	Rank
(T_{on}) ms	2	21.47	10.733	2.76	18.7	2
(T_{off}) ms	2	10.72	5.362	1.24	9.3	3
(V_g) V	2	76.57	38.287	24.08	66.0	1
(I) Amps	2	5.865	2.932	0.68	5.0	4
Error					1	
Total	8	114.625	57.314		100	

Table 11. ANOVA results for Electrode wear rate (TWR) when EN-31 is machined with Aluminium- Bronze Electrode.

Parameters	DOF	Sum of Squares	Mean-Variance	F – Ratio	% of P	Rank
(T_{on}) ms	2	23.10	11.548	3.05	20.24	4
(T_{off}) ms	2	26.73	13.363	3.67	23.42	3
(V_g) V	2	33.63	16.814	5.01	29.47	1
(I) Amps	2	30.65	15.324	4.41	26.86	2
Error					0.0001	
Total	8	114.611	57.049		100	

Based on the S/N calculations and ANOVA results the ranks are given for all input variables depending on its effect on the MER, TWR and SR.



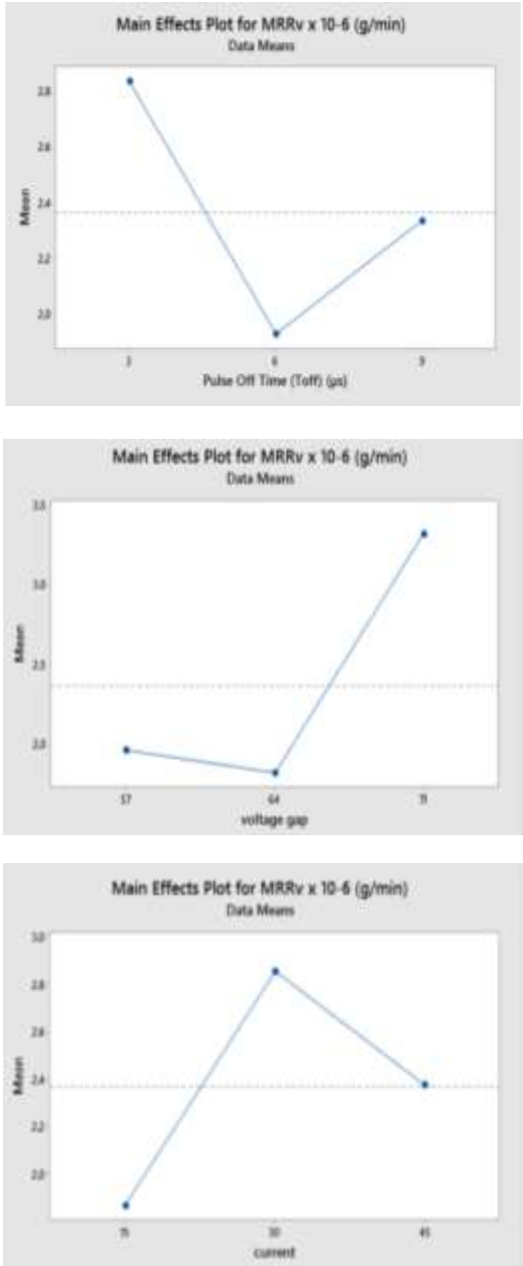
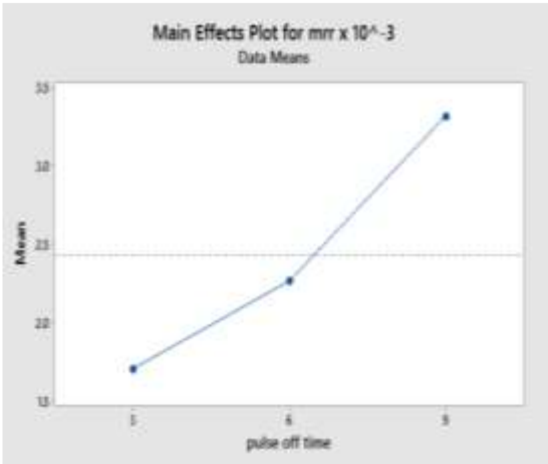
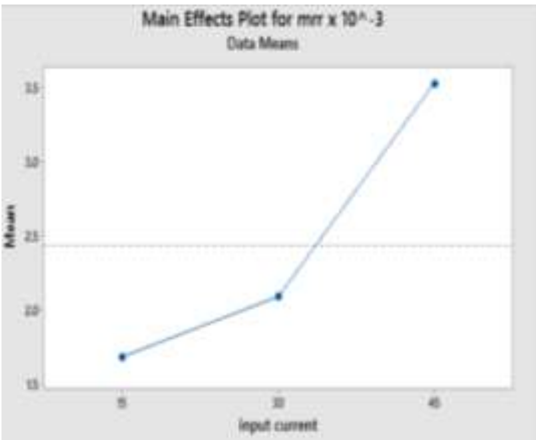


Fig. 3. Main effect plots of (MER) for all input factors when machined with the pure Copper electrode





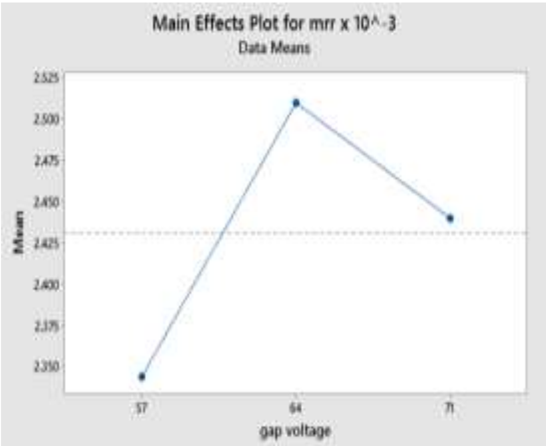
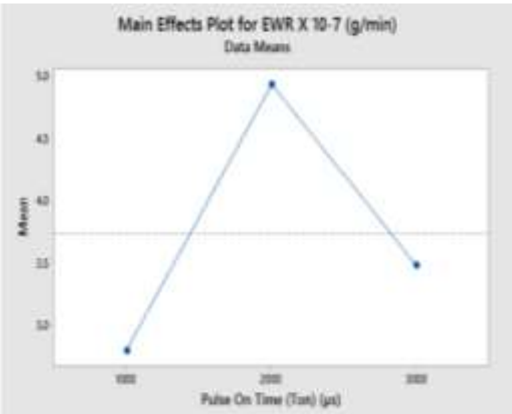
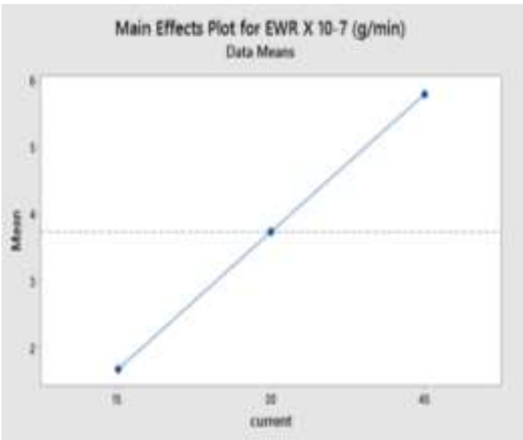


Fig. 4. Main effect plots of (MER) for all input factors when machined with Al-Bronze alloy electrode





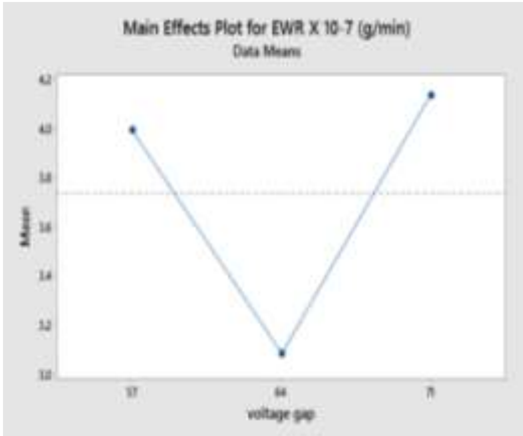
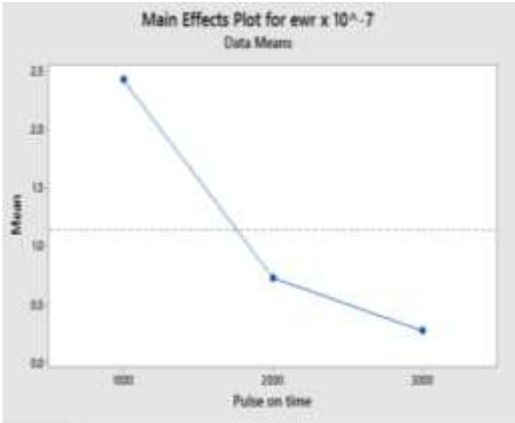
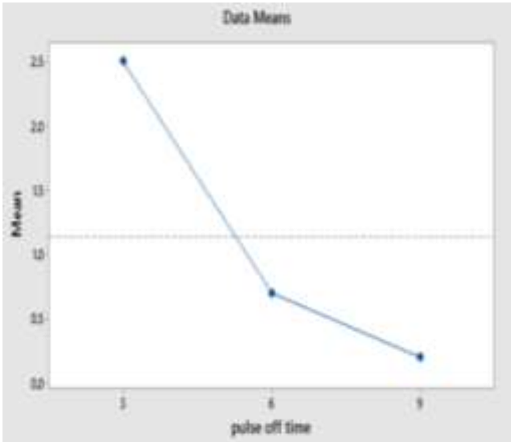
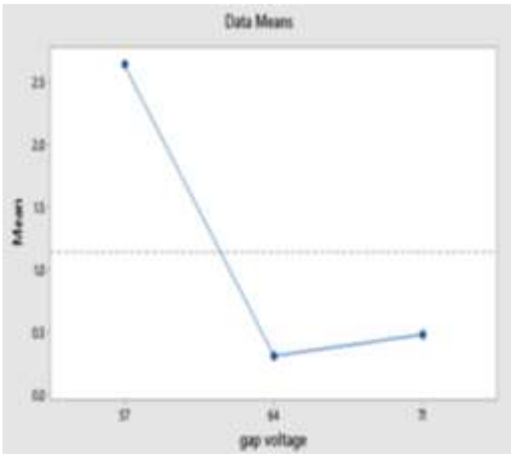


Fig. 5. Main effect plots of (EWR) for all input factors when machined with the pure Copper electrode







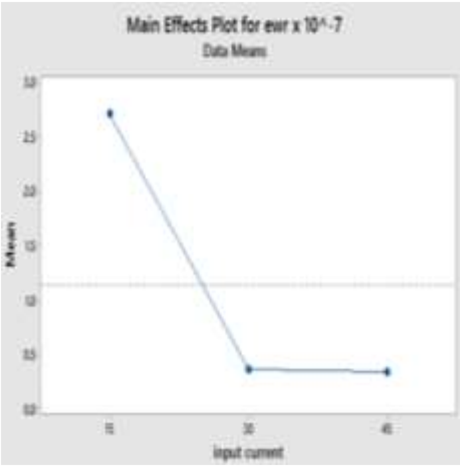


Fig. 6.Main effect plots of (EWR) for all input factors when machined with Al-Bronze alloy electrode

Table 12. S/N ratios for SR when EN-31 is machined with Pure Copper Electrode.

Level	(T_{on}) µs	(T_{off}) µs	(V_g) v	(I_p) Amps
1	**-9.199**	-10.843	-9.772	-10.252
2	-12.877	-10.651	-11.746	-10.301
3	-9.924	-10.505	-10.239	-11.446
DELTA	3.677	0.338	1.974	1.193

Table 13. S/N ratios for SR when EN-31 is machined with Aluminium Bronze Electrode

Level	(T_{on}) µs	(T_{off}) µs	(V_g) v	(I_p) Amps
1	-24.28	-23.68	-23.51	-24.04
2	-24.15	**-23.60**	-24.07	-24.37
3	-24.65	-25.64	-25.39	-24.66
DELTA	0.37	2.04	1.88	0.62

Table 14. ANOVA results for SR when EN-31 is machined with Pure Copper Electrode

Parameters	DOF	Sum of Squares	Mean-Variance	F – Ratio	% of P	Rank
(T_{on}) ms	**2**	**13.305**	**6.652**	**18.02**	**68.0**	**1**
(T_{off}) ms	2	0.523	0.261	0.29	2.0	4
(V_g) V	2	2.030	1.015	1.21	17.0	3
(I) Amps	2	3.450	1.725	2.21	10.0	2
Error					3	
Total	8	19.308	9.654		100	

Table 15. ANOVA results for SR when EN-31 is machined with Aluminium- Bronze Electrode

Para-meters	DOF	Sum of Squares	Mean-Variance	F–Ratio	% of P	Rank
(T_{on}) ms	2	4.440	2.220	0.33	0.026	4
(T_{off}) ms	**2**	**92.68**	**4.342**	**15.23**	**0.5592**	**1**
(V_g) V	2	62.50	31.250	7.27	0.3771	2
(I) Amps	2	6.092	3.046	0.46	0.00367	3
Error					0.0011	
Total	8	165.172	40.858		100	

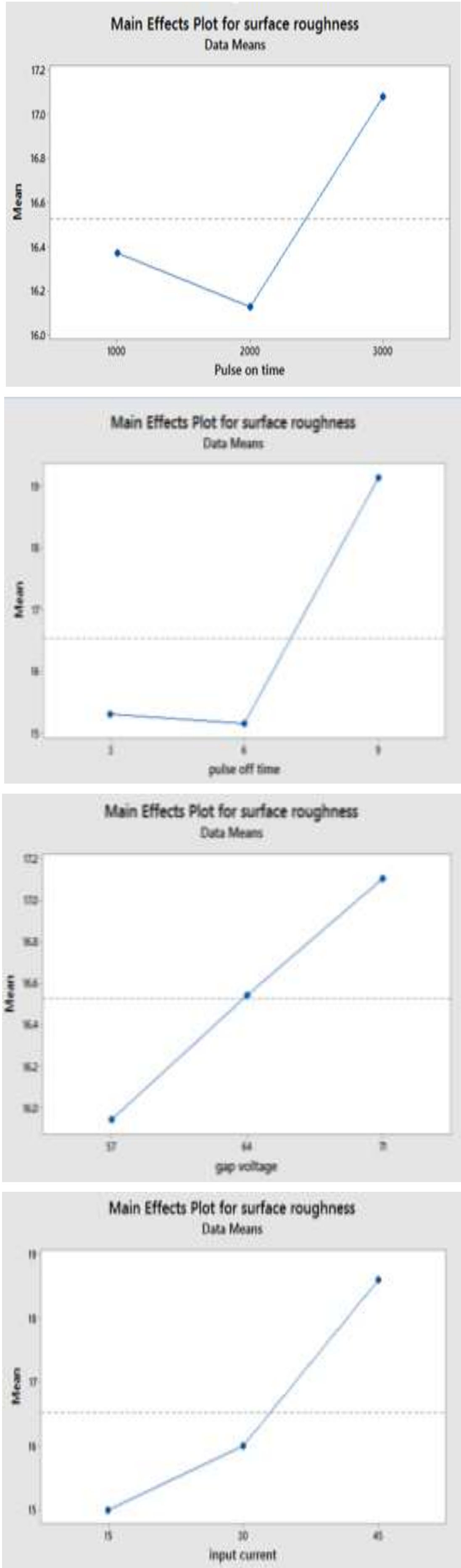


Fig. 7. Main effect plots of (SR) for all input factors when machined with the pure Copper electrode

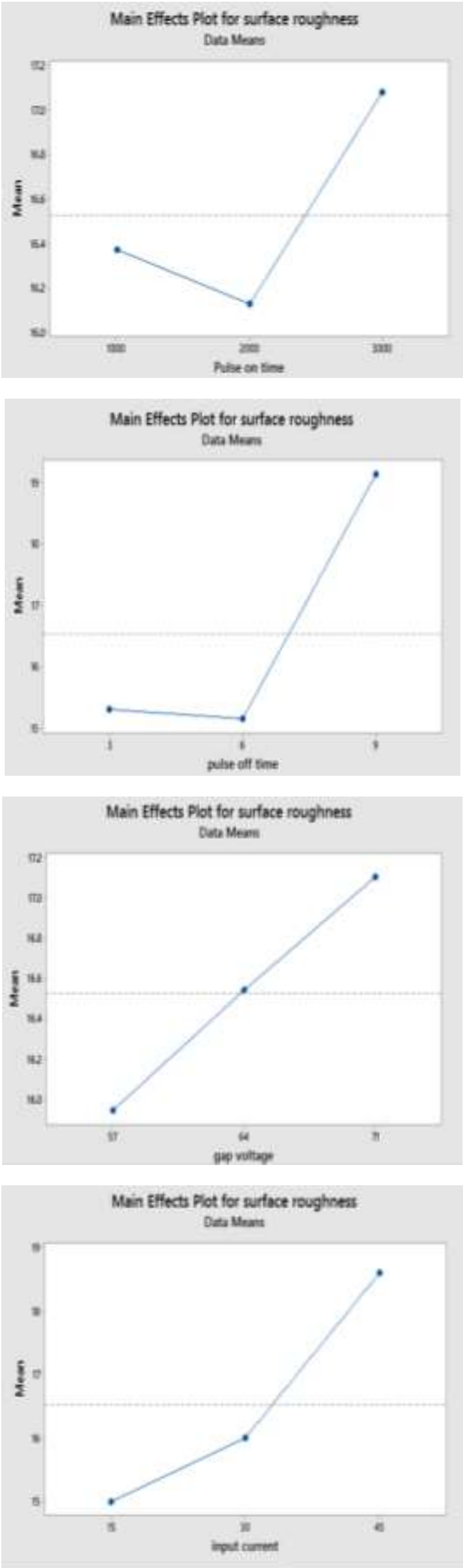


Fig. 8. Main effect plots of (SR) for all input factors when machined with Al-Bronze alloy electrode

Figures 3 and 4 are the mean effect plots of Material erosion rate (MER) of EN-31 machined with pure Copper and Al-Bronze alloy electrodes. The results have shown that MER is most affected by Voltage gap (V_g) in case of Copper Electrode and by Input current (I_p) in case of Aluminium Bronze electrode. From Figures 5&6 it is proved that electrode wear rate (EWR) or Tool wear rate is most affected by Input current (I_p) in case of Copper Electrode and by Input current (I_p) in case of Aluminium Bronze electrode. Finally, the mean effect plot of Surface roughness (SR) is most affected by Pulse on time (T_{on}) in case of Copper Electrode, by Pulse off Time (T_{off}).

6. CONCLUSIONS

The Primary idea of this work is to estimate the performance of ESM process and the effect of its input parameters on the outputs using a Taguchi design methodology. The results of ANOVA and S/N ratio calculations conclude the following remarks on this study.

Taguchi methodology adopted in this study helps to arrange input parameters in a structured way. Orthogonal array 9 was considered for arranging the combinations without repetitions. Usage of Taguchi DOE has given a satisfying result by decreasing the number of iterations and creating all possible combinations with minimum error. The ESM process was used to study the variation of Material erosion rate, Tool wear rate and Surface roughness under all possible machining conditions. MER & TWR are estimated by considering weights of the specimens before and after each machining condition. The MER is comparatively high when Aluminium Bronze Electrode compared to Pure Copper Electrode in the machining of EN-31. The surface finish obtained in case of machining with Copper Electrode is far better than that of Aluminium Bronze Electrode. Hence, the Copper material can be implied for those applications where a fine finish is required and Aluminium Bronze for a quick machining irrespective of its Surface Finish.

Copper electrode takes much longer time to machine EN-31 tool steel material for a particular machining condition as compared to Aluminium Bronze material; hence its usage depends on the situational demand of the operation. From S/N ratios, it is identified that MER is most influenced by V_g while machining with Copper Electrode, and by Input current (I_p) in case of Aluminium Bronze electrode. Electrode Wear Rate/ Tool wear rate (EWR/TWR) is most affected by Input current (I_p) while machining with Copper Electrode, and by Input current (I_p) in case of Aluminium Bronze electrode. Surface finish is mostly affected by Pulse on time (T_{on}) in case of Copper Electrode, by Pulse off Time (T_{off}) in case of Aluminium Bronze.

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8. NOMENCLATURE

ESM-Electric Spark Machine;
MER- Material Erosion Rate;
DOE-Design of Experiments;
T_{on}- Pulse on time;
T_{off}- Pulse off time;
V_g-Voltage Gap;
I_p-Input current;
SR-Surface Roughness;
EWR- Electrode Wear Rate;
OA-Orthogonal array;
ANOVA-Analysis of Variance;
S/N- Signal to Noise Ratio

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