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Parametric Optimization of Electro Discharge Machining of EN-24(PEARLITE & FERRITE + 40% BAINITE) Alloy Steel Material using Taguchi Technique

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Abstract—*EDM has become an important and cost-effective method of machining extremely tough and brittle electrically conductive materials. It is widely used in the process of making moulds and dies and sections of complex geometry and intricate shapes. The work piece material selected in this experiment is EN-24(PEARLITE & FERRITE + 40% BAINITE) alloy steel taking into account its wide usage in industrial applications. In today's world EN-24(PEARLITE & FERRITE + 40% BAINITE) alloy steel contributes to almost half of the world's production and consumption for industrial purposes. The input variable parameters are current, pulse on time and duty cycle. With the help of MINITAB software an orthogonal array of input variables was created using the design of experiments (DOE). The effect of the variable parameters mentioned above upon machining characteristics such as material removal rate (MRR), tool wear rate (TWR)) is studied and investigated. The tool material is copper, brass, graphite*

Keywords*: EDM, electrode, pulse on time, MRR, TWR*

1. INTRODUCTION

Non-traditional machining has grown out of the need to machine exotic engineering metallic materials, composite materials and high tech ceramics having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity. Electric discharge machinery developed in late 1940's has been accepted worldwide as a standard process in manufacturing and is capable of machining geometrically complex or hard material components, that are precise and difficult-to-machine such as heat treated tool steels, composites, super alloys, ceramics, has alloys, nitralloy, carbides, heat resistant steels etc. Being widely used in die and mold making industries, aerospace, aeronautics and nuclear industries EN-24(PEARLITE & FERRITE + 40% BAINITE) is the most preferred material for forging components consequently; an analysis on the influence of current and pulse duration and duty cycle over MRR and TWR was performed. EDM is now unquestionably recognized as an important precision machine tool forming process for producing internal shapes on work piece, this study present experimental analysis based on mixed design. The objective of this research is to study the performance of different electrode materials on EN-24(PEARLITE & FERRITE + 40% BAINITE) work piece with EDM process.

2. EXPERIMENTAL MATERIALS AND EQUIPMENTS

2.1 Tool material

The work piece material was a EN-24(PEARLITE & FERRITE + 40% BAINITE) The electrode materials were graphite, copper and brass. The chemical composition of electrode materials which is show in Table 1

Table1: Chemical composition of Electrode materials

Composition in %	Copper	Brass
Copper	99.750	56.700
Aluminum	0.040	0.025
Tin	0.030	0.020
Phosphorous	0.030	0.020
Lead	0.009	3.000
Iron	0.015	0.100
Zinc	0.060	39.850
Nickel	0.010	0.0770

Fig. 1: Shows brass,cupper graphite electrode(dia 15mm)

2.2 Work material

Specimens were prepared through normalizing process by taking pre heating temperature 860°c and time in preheating zone is 2 hours and soaking temperature is 880°c and soaking time is 1.2hours(80 minutes)this process give a distributed pearlite in ferrite matrix with 40% barite with a hardness 363BHN .

Fig. 2: Shows EN-24 work piece

2.3 Die-sinking EDM machine

The equipment used to perform the experiments was a die-sinking EDM machine of type SE-35 Electra plus 500x300. a jet flushing system in order to ensure the adequate flushing of the EDM process debris from the gap zone is employed. Pressure of the dielectric fluid is adjusted manually at the beginning of the experiment. The dielectric fluid used for the EDM machine was EDM oil-30, which is commercially available dielectric fluid. Polarity of the electrode is negative and that of the work piece is positive.

Fig. 3: Electronica SE-35 EDM machine

3. EXPERIMENTAL DETAILS

This paper uses Taguchi method, which is very effective to deal with responses influenced by multi-variables. This method is a powerful Design of Experiments tool, which provides a simple, efficient and systematic approach to determine optimal machining parameters. Compared to the conventional approach to experimentation, this method reduces drastically the number of experiments that are required to model the response functions. Traditional experimentation involves one-factor-at-a-time experiments, wherein one variable is changed while the rest are held constant. The major disadvantage of this strategy is that it fails to consider any possible interactions between the parameters. Taguchi technique overcomes all these drawbacks. The main effect is the average value of the response function at a particular level of a parameter. The effect of a factor level is the deviation it causes from the overall mean response. The Taguchi method is devised for process optimization and identification of optimal combinations of factors for given responses. The steps involved are: 1. Identify the response functions and the process parameters to be evaluated. 2. Determine the number of levels for the process parameters and possible interaction between them. 3. Select the appropriate orthogonal array and assign the process parameters to the orthogonal array and conduct the experiments accordingly. 4. Analyze the experimental results and select the optimum level of process parameters. 5. Verify the optimal process parameters through a confirmation experiment. The process parameters chosen for the experiments are: (a) pulse-on time (ton), (b) peak current (*I*p), and (c) duty factor(t) and three electrode Copper, brass, graphite while the response functions are: (a) electrode wear rate (EWR) and (b) material removal rate (MRR).According to the capability of the commercial EDM machine available and general recommendations of machining conditions for EN-24(PEARLITE & FERRITE + 40% BAINITE) the range and the number of levels of the parameters are selected as given in

Table 2: Level values of input Factors

Control Factors	1	2	3
Peak Current(Ip),amp	5	10	15
Electrode	cupper	Brass	Graphite
on time (Ton) µsec.	200	500	1000
Duty cycle(T)	9	10	11

A Taguchi design or an orthogonal array the method is designing the experimental procedure using different types of design like, two, three, four, five, and mixed level. In the study, a four factor mixed level setup is chosen with a total of eighteen numbers of experiments to be conducted and hence the OA L18 was chosen. This design would enable the two factor interactions to be evaluated. As a few more factors are to be added for further study with the same type of material, it was decided to utilize the L18 setup, which in turn would reduce the number of experiments at the later stage.

4. EXPERIMENTAL PROCEDURE

Experiments are performed, randomly, according to the L18 orthogonal array, on a EN-24(PEARLITE & FERRITE + 40% BAINITE). For each experiment a separate electrode is used. The machining time is 15 minutes for all experiments. The machining time is noted from the timer of the machine. The electrode wear rate is calculated by weight difference of the electrodes using automatic weighing machine with 300 g capacity with a precision of 0.0001g. The experimental results for TWR, MRR based on L18 orthogonal array is shown in table-3

Table 3: Shown MRR and TWR

EXP.NO	MRR(gm/m)	TWR(gm/m)
1	0.0580	0.0130
2	0.0520	0.1400
3	0.1026	0.0035
4	0.0413	0.0370
5	0.1370	0.0053
6	0.0353	0.0067
7	0.0213	0.0010
8	0.0760	0.0066
9	0.1080	0.0950
10	0.0760	0.1080
11	0.0200	0.0022
12	0.2110	0.0069
13	0.2220	0.0097
14	0.0253	0.0240
15	0.0690	0.0057
16	0.1630	0.0074
17	0.3230	0.0092
18	0.0206	0.0216

5. RESULTS AND DISCUSSION

After the experimental procedure, different response factors like MRR, TWR calculated from the observed data. Then a statistical analysis were performed on the calculated values and the signal to noise ratio values of three response factors are tabulated in table 4.

Table 4: Show S/N Ration for MRR and TWR

Sr. No	S/N Ratio for MRR	S/N Ratio for TWR
1	-24.7314	37.7211
2	-25.6799	17.0774
3	-19.7771	49.1186
4	-27.6810	28.6360
5	-17.2656	45.5145
6	-29.0445	43.4655
7	-33.4202	60.0000
8	-22.3837	43.6355
9	-19.3315	20.4455
10	-22.3837	19.3315
11	-33.9794	53.1515
12	-13.5144	43.2230
13	-13.0729	40.2646
14	-31.9376	32.3958
15	-23.2230	44.9437
16	-15.7562	42.6154
17	-9.8159	40.7621
18	-33.7227	33.3109

5.1 Effect of input factors on MRR

The response table for signal to noise ratio for MRR is shown in table 5 and corresponding analysis variances (ANOVA) table is shown in table 6 for MRR, the calculation of S/N ratio follows "Larger the better model".

Table 5: Response table for signal-to- noise ratio for MRR

Level	material	T	Ton	Current
1	-26.79	-23.95	-20.42	-31.14
2	-18.76	-22.81	-23.93	-21.37
3	-23.90	-22.69	-25.10	-16.94
Delta	8.03	1.26	4.68	14.20
Rank	2	4	3	1

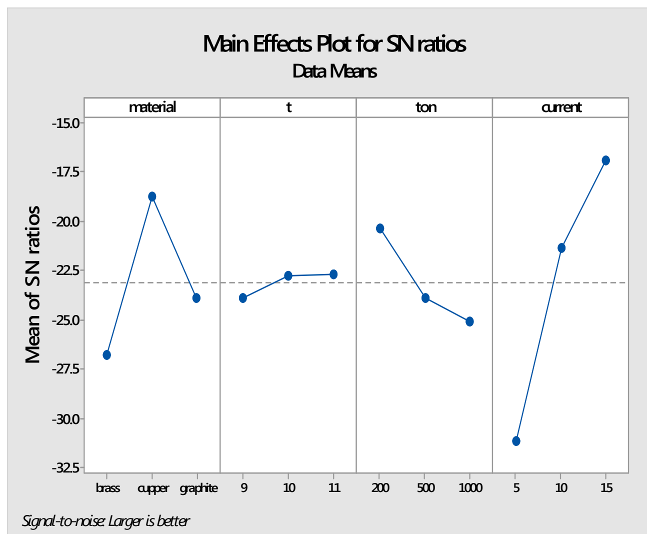

Fig. 4: Shows main effect plot for MRR

Table 6: Analysis of Variance for MRR

Source	DF	Seq SS	F	Pn	% contribution
Material	2	198.48	15.98	0.001	20.570
T	2	5.811	0.47	0.641	0.006
TON	2	71.137	5.73	0.025	7.370
Current	2	633.21	50.97	0.000	65.600
Residual Error	9	55.900	-----	-------	5.700
Total	17	964.55	-----	------	--------

Referring table 6 it is noticed that factor peak current (Ip) has largest contribution to the total sum of squares i.e. 65.6%. The factor pulse-on time (Ton) and material also have the considerable contribution in total sum of the squares which is 7.37% and 20.57 respectively. The factor duty cycle (T) has much less contribution of 0.006 %. The larger the contribution of any factor to the total sum of squares, the larger is the ability of that factor to influence material removal rate (MRR). So peak current (Ip) has maximum effect on material removal rate, Pulse on time (Ton) and material have considerable effect on material removal rate whereas duty cycle (t) has very less effect on MRR shown in fig

5.2 Model Analysis of MRR

The coefficients of model for S/N ratios for MRR are shown in Table -7. The parameter R2 describes the amount of variation observed in MRR is explained by the input factors. R2 = 94.2% indicate that the model is able to predict the response with high accuracy. Adjusted R2 is a modified R2 that has been adjusted for the number of terms in the model. If unnecessary terms are included in the model, R2 can be artificially high, but adjusted R2 (=89.1 %.) may get smaller. The standard deviation of errors in the modeling, S=2.492. Comparing the p-value to a commonly used α-level = 0.05, it is found that if the p-value is less than or equal to α, it can be concluded that the effect is significant (shown in bold), otherwise it is not significant

Table 7: Estimated Model Coefficients for MRR

Term	Coef	SE Coef	T	P
Constant	-23.1512	0.5874	-39.412	0.000
material brass	-3.6382	0.8307	-4.380	0.002
material cupper	4.3907	0.8307	5.285	0.001
t 9	-0.8005	0.8307	-0.964	0.360
t 10	0.3404	0.8307	0.410	0.692
ton 200	2.7284	0.8307	3.284	0.009
ton 500	-0.7767	0.8307	-0.935	0.374
current 5	-7.9881	0.8307	-9.616	0.000
current 10	1.7781	0.8307	2.140	0.061
S = 2.492	R-Sq = 94.2%	R-Sq(adj) = 89.1%	--------	-------

The regression equation is-

MRR = -0.248 + 0.01313 current - 0.000044 ton + 0.0240 t

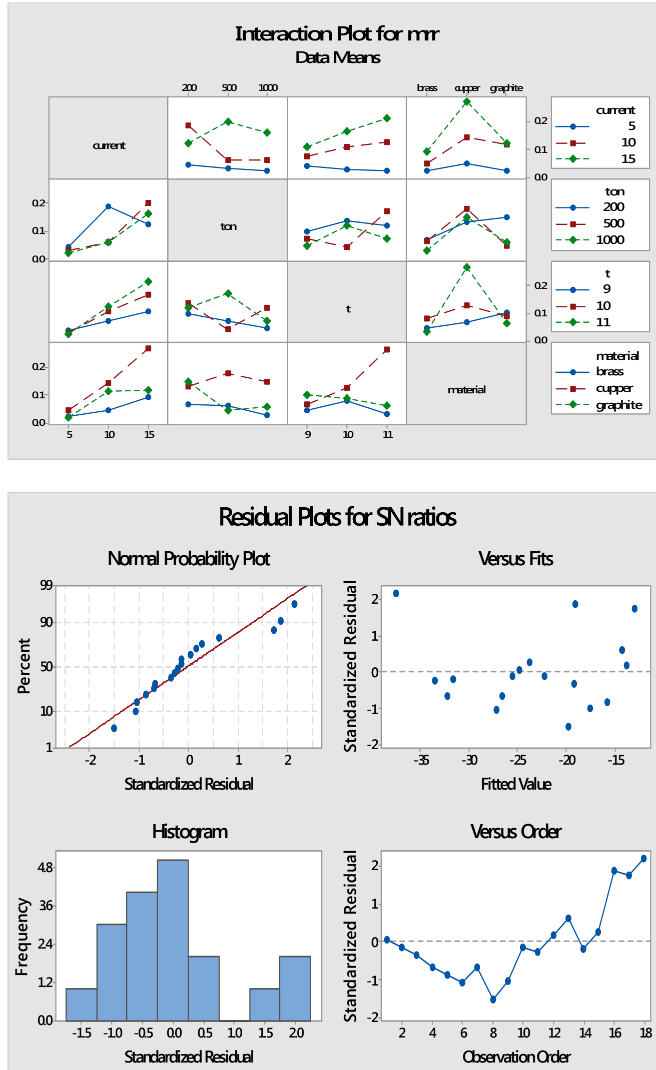

Fig. 5: Shows interaction and residual plot for MRR

5.3 Effect of input factors on TWR

The response table for signal to noise ratio for MRR is shown in table 4 and corresponding analysis variances (ANOVA) table is shown in table -8 for MRR, the calculation of S/N ratio follows "SMALLER the better model"

Table 8: Response table for signal-to- noise ratio for TWR

Level	Material	current	Ton	T
1	25.20	43.34	36.99	37.41
2	41.51	36.69	37.60	36.17
3	49.22	35.91	41.35	42.36
Delta	24.02	7.43	4.37	6.19
Rank	1	2	4	3

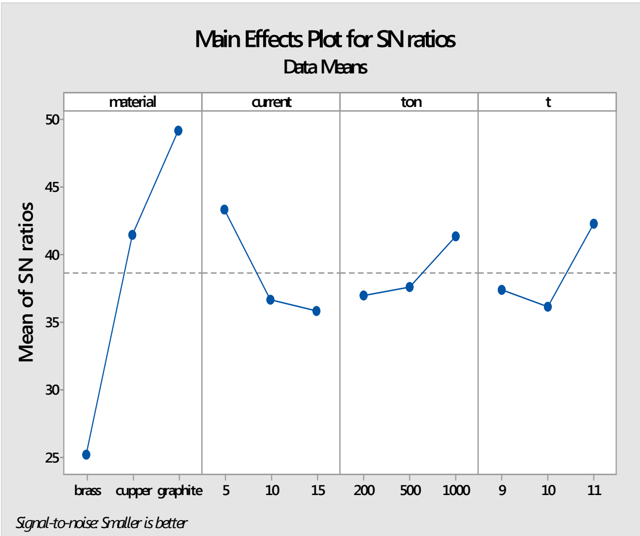

Fig. 6: Shows main effect plot for TWR

Table 9: Analysis of Variance for TWR

Source	Seq SS	F	P	% contribution
Material	1805.4	88.77	0.000	78.70
T	200.28	9.85	0.005	8.70
TON	67.10	3.30	0.084	2.90
Current	128.54	6.32	0.019	5.60
Residual Error	91.53	--------	---------	3.99
Total	2292.9	--------	---------	------

Referring table-9 it is noticed that material has largest contribution to the total sum of squares i.e. 78.7%. The factor duty cycle and current also have the considerable contribution in total sum of the squares which is 8.7% and 5.6% respectively. The factor pulse on time (Ton) has much less contribution of 2.9%. The larger the contribution of any factor to the total sum of squares, the larger is the ability of that factor to influence tool wear rate (TWR). So material has maximum effect on tool wear rate, duty cycle and current have considerable effect on tool rate whereas pulse on time (ton) has very less effect on TWR shown in fig

5.4 Model Analysis of TWR

The coefficients of model for S/N ratios for TWR are shown in Table-10. The parameter R2 describes the amount of variation observed in TWR is explained by the input factors. R2 = 96.0% indicate that the model is able to predict the response with high accuracy. Adjusted R2 is a modified R2 that has been adjusted for the number of terms in the model. If unnecessary terms are included in the model, R2 can be artificially high, but adjusted R2 (=92.5 %.) may get smaller. The standard deviation of errors in the modeling, S=3.189.Comparing the p-value to a commonly used α-level = 0.05, it is found that if the p-value is less than or equal to α, it can be concluded that the effect is significant (shown in bold), otherwise it is not significant

Table 10: Estimated Model Coefficients for SN ratios

Term	Coef	SE Coef	T	P
Constant	38.645	0.7517	51.414	0.000
material brass	-13.446	1.0630	-12.649	0.000
material cupper	2.867	1.0630	2.697	0.025
current 5	4.696	1.0630	4.417	0.002
current 10	-1.957	1.0630	-1.841	0.099
ton 200	-1.659	1.0630	-1.561	0.153
ton 500	-1.048	1.0630	-0.986	0.350
t 9	-1.236	1.0630	-1.162	0.275
t 10	-2.475	1.0630	-2.328	0.045
S = 3.189	R-Sq = 96.0%	R-Sq(adj) = 92.5%	--------	-------

Regression Equation

TWR = 0.078 + 0.00270 current - 0.000020 ton - 0.0065 t

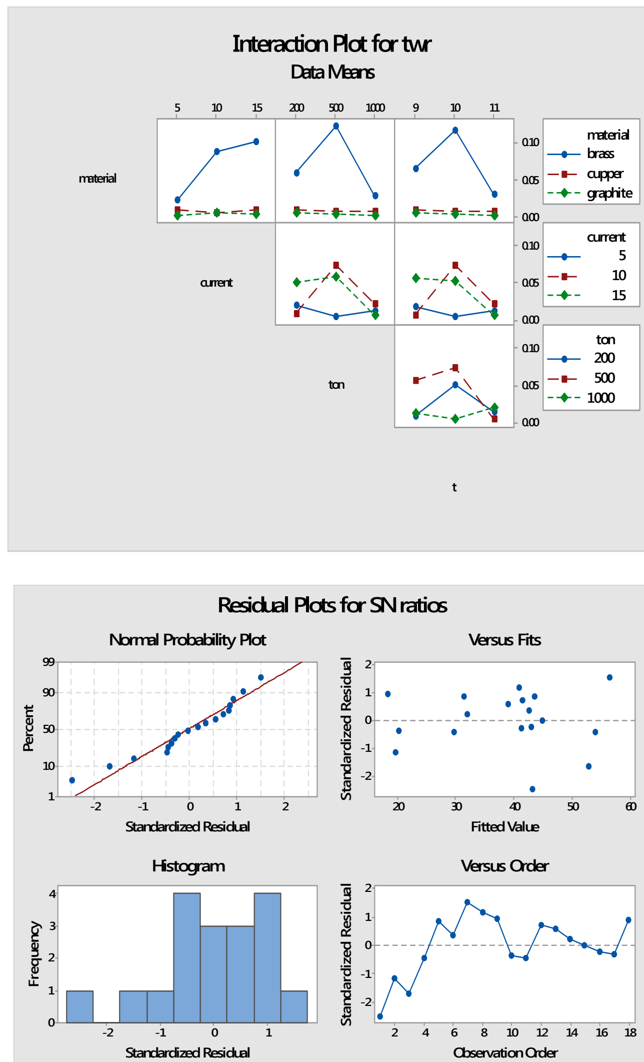

Fig. 7: Shows interaction and residual plot for TWR

6. CONCLUSION

The present work shows the use of taguchi method to find out optimal machining parameter. The s/n ratio for the test results were found out using the taguchi method. Machining parameters namely material, peak current (Ip), duty cycle (t) and pulse on time (Ton) is optimized to meet the objective. As a result of the study the following conclusions are drawn

1. The results reveal that the primary factor affecting the MRR is peak current subsequently followed by material, pulse on time and duty cycle and in case of TWR the primary factor affecting TWR is material then peak current then duty cycle and at last pulse on time

2. The optimized factor are the MRR is cupper, duty cycle (t) =11, pulse on time=200µsecond, peak current=15amp and for TWR the optimized factors are brass, peak current=15amp, pulse on time (ton) =200µsecond, duty cycle (t) =10

So now it is found by this research how to use taguchi parameter design to obtain optimum condition with lowest cost, minimum number of experiment s and industrial engineer can use this method.

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