International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Assessment of some factors influencing MRR on the EDM of AISI 304 by Multi Hole Electrode

Maan Aabid Tawfiq[A*] and Saad Hameed Najem[A*]

[A]Department of Production Eng. and Metallurgy, University of Technology, Baghdad, Iraq

Accepted 16 July 2014, Available online 01 Aug 2014, **Vol.4, No.4 (Aug 2014)**

Abstract

AISI 304 stainless steel have a wide range of applications in the industrial field. The need for machining AISI 304 SS has not been eliminated fully. Productivity is one of the important machining characteristics of electrical discharge machining (EDM) and it is expressed as the material removal rate (MRR). In this investigation an attempt has been made to assess the influences of machining parameters on the machining of AISI 304 SS. Design of experiments (full factorial design) concept has been used for experimentation. The machining experiments were conducted on a die sinking EDM machine using copper electrode tool with two levels of factors. The factors considered were electrode shape, pulse current, pulse on time and pulse off time. A procedure has been developed to assess and optimize the chosen factors to attain maximum MRR by incorporating: (i) response table and response graph; (ii) normal probability plot; (iii) interaction graphs; (iv) analysis of variance (ANOVA) technique. The results indicated that electrode shape is a factor, which has greater influence on MRR, followed by pulse off time. Also the determined optimal conditions really increase the MRR on the machining of AISI 304 SS within the ranges of parameters studied.

Keywords*: EDM; AISI 304 SS; MRR; Response table; Response graph; ANOVA; Normal Probability Plot.*

1. Introduction

In recent years, the practice of hard and difficult to machine materials, due to its brilliant technological properties, is extensively used in various sectors in modern manufacturing industries. Owing to, its excellent properties and behavior in these applications even more challenging, its transformation and processing they present problems which limit the accuracy and rising production costs. Consequently, the machining of such material in an efficient manner is a challenge (S. K. Majhi et al, 2013).
Electro Discharge Machining (EDM) is a brilliant solution to this problem, it is generally used to machine difficult-to-machine materials, high strength, temperature resistant alloys and manufacturing of tools and dies for machining cavities and counter shaping and cutting, as long as the workpiece material is conductive (A. Dvivedi et al, 2008).It is an electro-thermal erosion process where material is removed by a successive trend of controlled rapid and repetitive discrete electrical discharges (sparks), produced by a DC pulse generator, taking place between tool and work piece electrodes submerged in a liquid dielectric medium (S. Assarzadeh and M. Ghoreishi, 2013). It is assertion that EDM is now the fourth most popular machining method after milling, turning, and grinding. However, the efficiency of machining is less in comparison to conventional machining performance of any process is characterized by its product quality and productivity. EDM process is very demanding but the mechanism of process is complex and far from completely understood. Therefore, it is hard to establish a model that can accurately predict the response (productivity, surface quality etc.) by correlating the process parameter, though several attempts have been made (M. K. Pradhan and C. K. Biswas, 2009).Since it is a very costly process, optimal setting of the process parameters are up most important to reduce the machining time to enhance the productivity (M. K. Pradhan and C. K. Biswas, 2008). Improving the MRR and surface quality are still challenging problems that restrict the expanded application of the technology (K. Wang et al, 2003). The selected AISI 304 stainless steel material for the present investigation is having a wide range of applications in the industrial field: Chemical, Pharmaceutical, Cryogenic, Food, Dairy, Paper industries etc. (P. S. Rao et al, 2010).

In the present work, a procedure has been developed to assess and optimize the chosen factors to attain maximum MRR by incorporating: (i) response table and response graph; (ii) normal probability plot; (iii) interaction graphs; (iv) analysis of variance (ANOVA) technique.

2. Scheme of investigation

In order to achieve the desired metal removal rate (MRR) on the AISI 304 SS workpiece, the present investigation has been planned in the following steps:
i. Identifying the important factors, which influence the metal removal rate on the machining of AISI 304 SS;

*Corresponding author: **Saad Hameed Najem**

Table 1: Important parameters and their levels

S. no	Parameter	Notation	Unit	Levels			
				Actual factors		Coded factors	
				Low	High	Low	High
1	Electrode shape	A	-	Mono	Multi -4channels	-1	+1
2	Pulse current	B	Amp.	30	36	-1	+1
3	Pulse on time	C	µsec.	100	150	-1	+1
4	Pulse off time	D	µsec.	50	75	-1	+1

ii. Finding the upper and lower limits of the factors identified;
iii. Developing the experimental design matrix using design of experiments;
iv. Conducting the experiments as per the design matrix;
v. Assessing the factors and its effects using response table and effect graph;
vi. Assessing the real or chance effect of factors using normal probability plot;
vii. Analyzing the results using ANOVA;
viii. Optimizing the chosen factor levels to attain maximum MRR.

2.1. Identifying the important factors

Based on the previous published results (R. Atefi et al, 2012; L. Li et al, 2012), the machining parameters, which are having significant effect on MRR. The machining parameters identified are: (i) electrode shape; (A), (ii) pulse current (B); (iii) pulse on time (C); (iv) pulse off time (D). Out of which electrode shape has been specially applied.

2.2. Finding the upper and lower limits of the factors identified

For finding the upper and lower limits of the machining parameters, a detailed analysis has been carried out. The limits identified are discussed below:
(i) The studies related to EDM of AISI 304 SS indicate that electrode shape is the factor, which highly influences the MRR. Also the increase of number of holes inside the electrode (to certain limit) increases the MRR. The higher number of holes leads to large MRR in the AISI 304 SS. In EDM of AISI 304 SS, during machining, at higher number of holes, large MRR it leads to high productivity (O. Yilmaz and M. A. Okka, 2010). For maintaining the proper MRR, the electrode shape has been set at reasonable level of being mono and multi 4 -channels.
(ii) Pulse current is another important factor which influences MRR. Higher pulse current causes a stronger spark, which results in more eroded material from the workpiece (M. Shabgard et al, 2011). In the present study, the Pulse current is 30 and 36.
(iii) The MRR increases with increase in pulse duration at all value of peak current. The MRR is a function of pulse duration but at low value of peak current, the MRR is low due to the insufficient heating of the material and also after pulse duration, the MRR increases less because of insufficient clearing of debris from the gap due to insufficient pulse interval (K. Sandeep, 2013).The pulse on time chosen between 100 and 150 µsec.
(iv) The MRR decreases when pulse-off time is increased this is because when Toff increases, there will be an undesirable heat loss which does not contribute to MRR. This will lead to drop in the temperature of the workpiece before the next spark starts and therefore MRR decreases (M. K. Pradhan and C. K. Biswas, 2008) and hence the pulse-off time has been selected at reasonable level and is 50 and 75 µsec.

2.3. Developing the experimental design matrix using design of experiments

An experiment is a series of trials or tests, which produces quantifiable outcomes. The experiment may be random or deterministic. For experimentation, design of experiment in statistics has been used. The merit of this experimental scheme is that the cost of experimentation is reduced considerably as compared to one factor at a time type experiment. The identified factors and its lower and upper limits are discussed in sections 2.1 and 2.2. In this experimental scheme, all possible combinations of levels are included so that there are 2n (where n refers to the number of factors, i.e., 24 = 16) trials in the experiment (A. N Sait et al, 2009). The notations, units and their levels chosen are summarized in Table 1. For easy recording and processing of experimental data, the parameters levels are coded as +1 and −1. The intermediate coded value of any levels can be calculated by using the following expression (S. Ravi et al, 2004):

$$X_i=\frac{X-\left[\frac{X_{max.}+X_{min.}}{2}\right]}{\left[\frac{X_{max.}-X_{min.}}{2}\right]} \qquad (1)$$

Where Xmax is the upper level of the parameter, Xmin is the lower level of the parameter and Xi is the required coded values of the parameter of any value of X from Xmin to Xmax.

2.4. Conducting the experiments

The Electrical Discharge Machining experiments were conducted at the Center of Training and Workshop at University of Technology, Iraq. The experiments were performed on a die sinking EDM machine (CHMER EDM CNC) which operates with an iso-pulse.

The workpiece material used in this study was AISI 304 stainless steel. Prior to EDM processing, the workpiece was square specimens 35 × 35 mm and 3 mm thick with a roughness Ra of 2 µm on the surface to be machined. The chemical composition of the workpiece material is given in Table 2.

Electrolytic copper cylindrical bars 100 mm long with a diameter of 30 mm were mounted axially in line with

Table 2: Chemical composition of 304 stainless steel workpiece

Material	C%	Si%	Mn%	Cr%	Ni%	Mo%	Cu%	Fe%
% weight	0.07	0.64	1.4	18.5	10.2	0.3	0.1	Balance

Table 3: Chemical composition of tool electrode

Material	Fe%	Si%	Sb%	Zn%	Sn%	Al%	P%	Cu%
% weight	0.015	0.01	0.002	0.004	0.004	0.004	0.002	Balance

Table 4: Design matrix and corresponding output response

Exp. No	Coded factors				Actual factors				MRR mm^3/min.
	A	B	C	D	A	B	C	D	
1	-1	-1	-1	-1	Mono	30	100	50	18.217
2	+1	-1	-1	-1	Multi 4 channels	30	100	50	25.140
3	-1	+1	-1	-1	Mono	36	100	50	20.617
4	+1	+1	-1	-1	Multi 4 channels	36	100	50	28.450
5	-1	-1	+1	-1	Mono	30	150	50	19.128
6	+1	-1	+1	-1	Multi 4 channels	30	150	50	26.397
7	-1	+1	+1	-1	Mono	36	150	50	20.816
8	+1	+1	+1	-1	Multi 4 channels	36	150	50	27.064
9	-1	-1	-1	+1	Mono	30	100	75	14.313
10	+1	-1	-1	+1	Multi 4 channels	30	100	75	19.751
11	-1	+1	-1	+1	Mono	36	100	75	16.476
12	+1	+1	-1	+1	Multi 4 channels	36	100	75	22.734
13	-1	-1	+1	+1	Mono	30	150	75	15.029
14	+1	-1	+1	+1	Multi 4 channels	30	150	75	20.739
15	-1	+1	+1	+1	Mono	36	150	75	16.815
16	+1	+1	+1	+1	Multi 4 channels	36	150	75	23.197

workpieces and used as tool electrode at positive polarity, through hole was drilled as shown in Fig. 1.

The gap between the electrode and the workpiece is 0.20 mm. The chemical composition of the electrode material is given in Table 3.

Commercial grade EDM oil was used as dielectric fluid. Pressure flushing with 0.3 Kg/cm^2 was used. A digital balance (DENVER INSTRUMENT) with a resolution of 0.1 mg was used for weighing the workpieces before and after the machining process. The metal removal rate MRR (mm^3/min.) is defined as the mass of metal removed M_2 from the original mass M_1 (g) divided by the density of workpiece ρ_w (g/mm^3), and T is the machining time (min). Eq. (2) show the calculations used for assessing the values of MRR. The design matrix and the corresponding responses are given in Table 4.

$$MRR = \frac{M_1 - M_2}{\rho_w T} \quad (2)$$

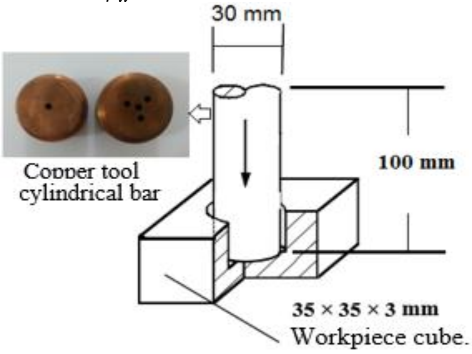

Fig. 1: Geometry of the tool electrode and the workpiece.

3. Assessing the factors and its effects

Assessing the factors and its effects on MRR of AISI 304 SS machining process has been carried out through: (i) response table and response graph; (ii) normal probability plot; (iii) analysis of variance (ANOVA) technique.

3.1. Response table and response graph

The influence of machining parameters on MRR has been performed using response table. Response tables are used to simplify the calculations needed to analyze the experimental data. In response table, the effect of a factor on a response variable is the change in the response when the factor goes from its low level to its high level. The complete response table for a two level, 16 run full factorial experimental design is shown in Table 5. If the effect of a factor is greater than zero, the average response is higher for the higher level of the factor than for the low level. However, if the estimated effect is less than zero, it indicates that the average response is higher at low level of the factor than at high level. If the effect for a factor is very small, then it is probably because of random variation than a real factor effect. The graphical display such as response graph can be used, in conjunction with a response table, to identify appropriate settings for machining parameters to maximize the average MRR (S. Ravi *et al*, 2004). The effect of main and interaction factors derived from the response table for machining process is plotted in Fig. 2. The procedure involved in the construction of a response table and response graph is explained elsewhere (T. Barker, 1985). From Fig. 2, it is

Table 5: Response table for metal removal rate

S. No	MRR	A		B		C		D		AB		AC		AD	
	mm^3/min.	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1
1	18.217	18.217		18.217		18.217		18.217			18.217		18.217		18.217
2	25.14		25.14	25.14		25.14		25.14		25.14		25.14		25.14	
3	20.617	20.617			20.617	20.617		20.617		20.617			20.617		20.617
4	28.45		28.45		28.45	28.45		28.45			28.45	28.45		28.45	
5	19.128	19.128		19.128			19.128	19.128			19.128	19.128			19.128
6	26.397		26.397	26.397			26.397	26.397		26.397			26.397	26.397	
7	20.816	20.816			20.816		20.816	20.816		20.816		20.816			20.816
8	27.064		27.064		27.064		27.064	27.064			27.064		27.064	27.064	
9	14.313	14.313		14.313		14.313			14.313		14.313		14.313	14.313	
10	19.751		19.751	19.751		19.751			19.751	19.751		19.751			19.751
11	16.476	16.476			16.476	16.476			16.476	16.476			16.476	16.476	
12	22.734		22.734		22.734	22.734			22.734		22.734	22.734			22.734
13	15.029	15.029		15.029			15.029		15.029		15.029	15.029		15.029	
14	20.739		20.739	20.739			20.739		20.739	20.739			20.739		20.739
15	16.815	16.815			16.815		16.815		16.815	16.815		16.815		16.815	
16	23.197		23.197		23.197		23.197		23.197		23.197		23.197		23.197
Average	20.93	17.676	24.18	19.84	22.02	20.71	21.15	23.23	18.63	20.84	21.02	20.98	20.88	21.21	20.65
Effect		6.504		2.18		0.44		-4.6		0.18		-0.1		-0.56	

S. No	BC		BD		CD		ABC		ABD		ACD		BCD		ABCD	
	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1
1		18.217		18.217		18.217	18.217		18.217		18.217		18.217			18.217
2		25.14		25.14		25.14		25.14		25.14		25.14	25.14		25.14	
3	20.617		20.617			20.617		20.617		20.617	20.617			20.617	20.617	
4	28.45		28.45			28.45	28.45		28.45			28.45		28.45		28.45
5	19.128			19.128	19.128			19.128	19.128			19.128		19.128	19.128	
6	26.397			26.397	26.397		26.397			26.397	26.397			26.397		26.397
7		20.816	20.816		20.816		20.816			20.816		20.816	20.816			20.816
8		27.064	27.064		27.064			27.064	27.064		27.064		27.064		27.064	
9		14.313	14.313		14.313		14.313			14.313		14.313		14.313	14.313	
10		19.751	19.751		19.751			19.751	19.751		19.751			19.751		19.751
11	16.476			16.476	16.476			16.476	16.476			16.476	16.476			16.476
12	22.734			22.734	22.734		22.734			22.734	22.734		22.734		22.734	
13	15.029		15.029			15.029		15.029		15.029	15.029		15.029			15.029
14	20.739		20.739			20.739	20.739		20.739			20.739	20.739		20.739	
15		16.815		16.815		16.815	16.815		16.815		16.815			16.815	16.815	
16		23.197		23.197		23.197		23.197		23.197		23.197		23.197		23.197
Average	21.2	20.66	20.85	21.01	20.83	21.03	21.06	20.8	20.83	21.03	20.828	21.032	20.78	21.08	20.82	21.04
Effect	-0.54		0.16		0.02		-0.26		0.2		0.204		0.3		0.22	

inferred that the larger the vertical line, the larger the change in MRR when going from level 1 to level 2 for a factor. It will be pointed out that the statistical significance of a factor is directly related to the length of the vertical line (see Fig. 2).

3.2. Normal probability plot

In response graph, it is found that some of the factor effects are larger than the other, but it is not clear, whether these results are real or chance. To identify the real effects, normal probability plot are used and is shown in Fig. 3. Normal plot is a graphical technique based on ‘‘Central limit theorem’’. The procedure for constructing the normal probability plot is given elsewhere (R. Lochner and J. Mater, 1990). The calculations required for constructing the graph is shown in Table 6. As per the normal probability plot, points which are close to a line fitted to the middle group of points represent estimated factors which do not demonstrate any significant effect on the response variable. On the other hand, the points appear to be far away from the straight line are likely to represent the real factor effects on the MRR. In Fig. 3, A, B and D are quite away from the straight line and are considered to be significant.

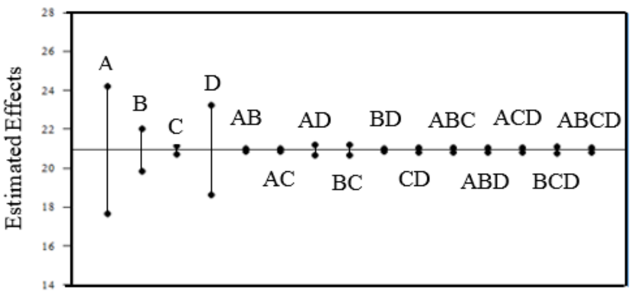

Fig. 2: Response graph.

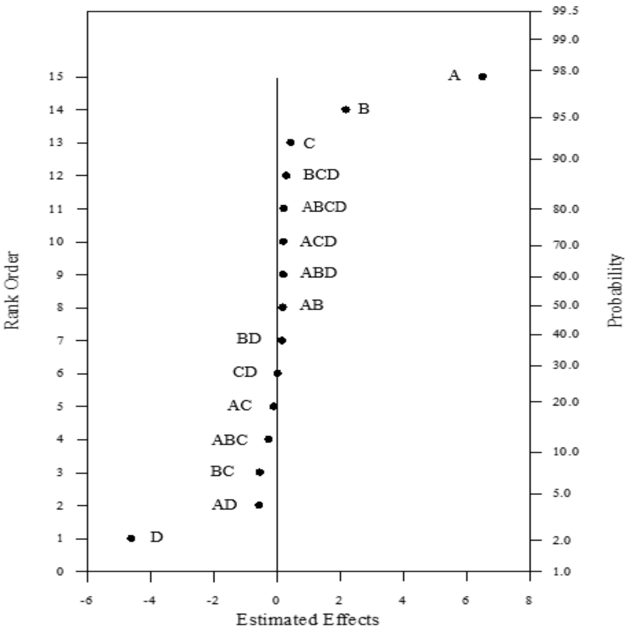

Fig. 3: Normal probability plot

3.3. Analysis of variance

Table 6: Calculation for normal probability plot

Factors	D [-1]	D[+1]
A[-1]	18.217	14.313
	20.617	16.476
	19.128	15.029
	20.816	16.815
	78.778/4=19.695	62.663/4=15.658
A[+1]	25.140	19.751
	28.450	22.734
	26.397	20.739
	27.064	23.197
	107.1/4=26.760	86.421/4=21.605

The normal probability plot has the disadvantage of not providing a clear criterion for what values for estimated effects indicate significant factor or interaction effects. In addition, how do we measure amount of departure from the straight line pattern .ANOVA meets this need by how much an estimate must differ from zero in order to be judged "statistically significant". The ANOVA result is presented in Table 7. This analysis has been carried out for a level of significance of 5%, i.e., for a level of confidence of 95%. From the ANOVA results, it is concluded that the factors *A*, *B*, *C*, *D* and their interactions *AD* and *BC* have significant effect on metal removal rate and *AB*, *AC*, *BD*, *CD* have no effect at 95% confidence level. As the interaction effect of *AD* and *BC* seems to be significant to the MRR, the average values of the MRR are calculated for all the combinations and are presented in Tables 8 and 9. By using the values of interaction, the significant interaction graphs are drawn for each combination of levels. The significant interactions between the parameters (*AD* and *BC*) are shown in Figs. 4 and 5. The insignificant interactions (*AB*, *AC*, *BD* and *CD*) are presented in Tables 10 and 13 and shown in Figs. 6 – 9. In these figures the lines are parallel to each other, which show that there is no interaction between parameters. By analyzing these figures also evident from ANOVA analysis, it has been concluded that *AD* is more interactive than *BC*.

Table 7: ANOVA test results

S. no	Factors	Estimated effects	Effect squared (E^2)	DOF	Mean square (MS)	F_{ratio}
1	A	6.504	42.302	1	42.302	738.254
2	B	2.180	4.752	1	4.752	82.932
3	C	0.44	0.193	1	0.193	3.368
4	D	-4.6	21.160	1	21.160	369.284
5	AB	0.18	0.032	1	0.032	0.558
6	AC	-0.1	0.010	1	0.010	0.174
7	AD	-0.56	0.313	1	0.313	5.462
8	BC	-0.54	0.291	1	0.291	5.078
9	BD	0.16	0.025	1	0.025	0.436
10	CD	0.02	0.0004	1	0.0004	00.69
11	ABC	-0.26	0.067			
12	ABD	0.2	0.040			
13	ACD	0.204	0.0416			
14	BCD	0.3	0.090			
15	ABCD	0.22	0.048			
Error				5	0.0573	

Table 8: Calculation for A and D interaction graphs

Factors	D [-1]	D[+1]
A[-1]	18.217	14.313
	20.617	16.476
	19.128	15.029
	20.816	16.815
	78.778/4=19.695	62.663/4=15.658
A[+1]	25.140	19.751
	28.450	22.734
	26.397	20.739
	27.064	23.197
	107.1/4=26.760	86.421/4=21.605

Table 9: Calculation for B and C interaction graphs

Factors	C [-1]	C[+1]
B[-1]	18.217	19.128
	25.140	26.397
	14.313	15.029
	19.751	20.739
	77.421/4=19.355	81.293/4=20.323
B[+1]	20.617	20.816
	28.450	27.064
	16.476	16.815
	22.734	23.197
	88.277/4=22.069	87.892/4=21.973

Table 10: Calculation for A and B interaction graphs

Factors	B [-1]	B[+1]
A[-1]	18.217	20.617
	19.128	20.816
	14.313	16.476
	15.029	16.815
	66.687/4= 16.672	74.724/4=18.681
A[+1]	25.140	28.450
	26.397	27.064
	19.751	22.734
	20.739	23.197
	92.027/4=23.007	101.45/4=25.361

Table 11: Calculation for A and C interaction graphs

Factors	C [-1]	C[+1]
A[-1]	18.217	19.128
	20.617	20.816
	14.313	15.029
	16.476	16.815
	69.623/4=17.406	71.788/4=17.947
A[+1]	25.140	26.397
	28.450	27.064
	19.751	20.739
	22.734	23.197
	96.0754=24.018	97.397/4=24.349

Table 12: Calculation for B and D interaction graphs

Factors	D [-1]	D[+1]
B[-1]	18.217	14.313
	25.140	19.751
	19.128	15.029
	26.397	20.739
	88.88/4=22.220	69.832/4=17.458
B[+1]	20.617	16.476
	28.450	22.734
	20.816	16.815
	27.064	23.197
	96.947/4=24.236	79.222/4=19.805

Table 13: Calculation for C and D interaction graphs

Factors	D [-1]	D[+1]
C[-1]	18.217	14.313
	25.140	19.751
	20.617	16.476
	28.450	22.734
	92.424/4=23.106	73.270/4=18.320
C[+1]	19.128	15.029
	26.397	20.739
	20.816	16.815
	27.064	23.197
	93.405/4=23.351	75.780/4=18.945

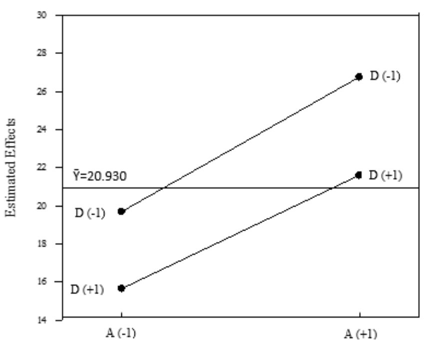

Fig. 4: Interaction between A and D

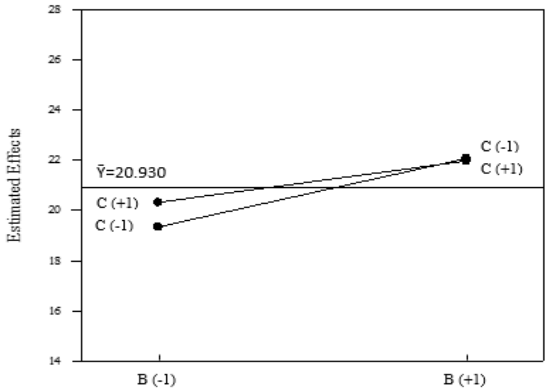

Fig. 5: Interaction between B and C

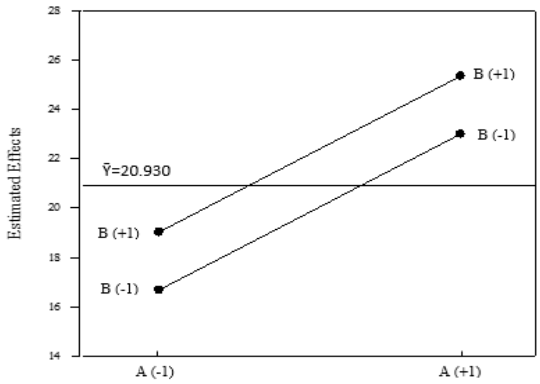

Fig. 6: Interaction between A and B

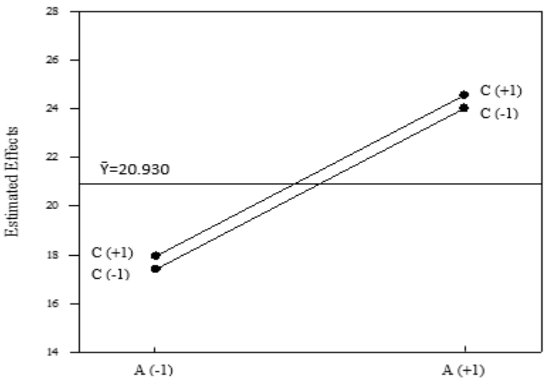

Fig. 7: Interaction between A and C

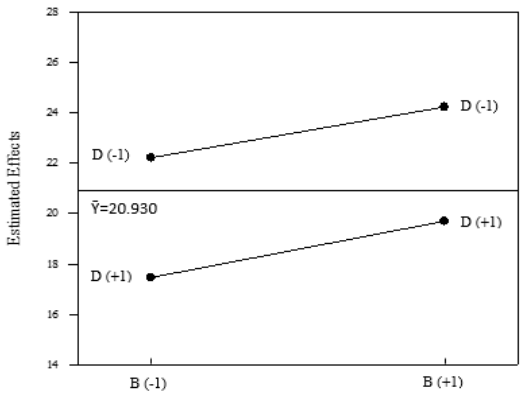

Fig. 8: Interaction between B and D

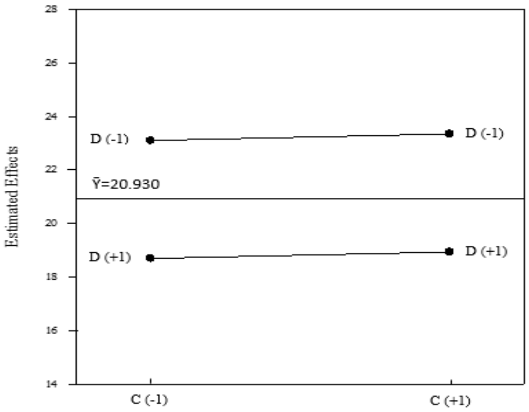

Fig. 9: Interaction between C and D

4. Optimizing the chosen factor levels to attain maximum metal removal rate

From the analysis of response graph, response table, and interaction graphs, the optimal machining parameters for the AISI 304 SS machining process is achieved for the maximum value of MRR. The optimal conditions arrived are:

(i) Electrode shape at high level (Multi – 4 channels).
(ii) Pulse current Pulse current at high level (36 Amp.).
(iii) Pulse on time at low level (50 µsec.).
(iv) Pulse off time at low level (50 µsec.).

Based on the above optimum conditions, the maximum value of MRR can be obtained from the following expression using the values form response table (Table 5) (S. Ravi *et al*, 2004; R. Lochner and J. Mater, 1990).

$$MRR_{(max.)} = [\text{grand mean}] + [\text{contribution of A}] + [\text{contribution of B}] + [\text{contribution of C}] + [\text{contribution of D}] + [\text{contribution of AD}] + [\text{contribution of BC}] \quad (3)$$

$$MRR_{(max.)} = \bar{Y} + [A_{(+1)} - \bar{Y}] + [B_{(+1)} - \bar{Y}] + [C_{(-1)} - \bar{Y}] + [D_{(-1)} - \bar{Y}] + [AD_{(-1)} - \bar{Y}] + [(BC_{(-1)} - \bar{Y})]$$

$$MRR_{(max.)} = 20.930 + [24.180 - 20.930] + [22.020 - 20.930] + [20.710 - 20.930] + [23.230 - 20.930] + [21.020 - 20.930] + [21.210 - 20.930] + [21.200 - 20.930]$$

$$MRR_{(max.)} = 28.340 \text{ mm}^3/\text{min}.$$

The above result reveals that the $MRR_{(max.)}$ on the machining of AISI 304 SS within the range of factor under investigation is 28.430 mm^3/min. To check the validity of this optimization procedure, the aforementioned MRR value is compared with the experimental values, obtained for the same optimized conditions and the variation is within the reasonable accuracy (+5%). Moreover, the equation mentioned earlier (3) can be effectively used to predict the MRR of EDMed AISI 304 SS drills at a 95% confidence level by multiplying the contributions with corresponding coded values of the main and interaction factors.

Discussions

The material removal rate depends not only on the workpiece material but on the material of the tool electrode and the machining parameters such as flushing pressure, pulse current, pulse on time, pulse off time etc. (H. El-Hofy, 2005).

From the results, it can be seen that the MRR is minimum at mono electrode shape. The MRR increases with the increase of number of holes inside the electrode. The reason being at multi 4 - channels, debris removed from efficient machining area more than mono hole thus multi 4 - channels brings fresh dielectric in the inter electrode gap.

The MRR observed at the pulse current of 36 Amp. is more than the MRR observed at lower pulse current. This is expected because an increase in pulse current produces strong spark, which produces the higher temperature, causing more material to melt and erode from the workpiece as it is concluded in Ref. (M. K. Pradhan, 2010).

It is clearly evident that with the increasing pulse-on-time, increase MRR. Higher pulse-on-time, i.e. spark energy for a longer time, results in larger craters on work piece and thus increases MRR. This finding has close relationship with the results presented by Ref. (P. S. Bharti, 2012).

Also the increase in pulse-off-time decreased the MRR as with long pulse-off time the dielectric fluid produces the cooling effect on electrode and work piece and hence decreases the MRR (M. K. Pradhan and C. K. Biswas, 2008).

The observed results shown proved that the main factor, which affects the MRR, is electrode shape. The pulse-on-time only plays small role on AISI 304 SS machining process.

The interaction between machining parameters also play a prominent role in machining of AISI 304 SS. In the present study, only two interactions namely AD and BC have significant effects.

Conclusion

Using experimental design, the process parameters influencing the MRR on the machining of AISI 304 SS has been assessed.

(1) This technique is convenient to predict the main effects and interaction effects of different influential combinations of machining parameters.
(2) Electrode shape is the factor, which has greater influence on MRR, followed by pulse off time.
(3) The interaction between electrode shape and pulse off time has more influence comparing with other interactions on MRR on the machining of AISI 304 SS.
(4) The parameters considered in the experiments are optimized to attain maximum MRR using response graph, response table, normal probability plot, interaction graphs and analysis of variance (ANOVA) technique.
(5) The optimization procedure can be used to predict the MRR for EDM of AISI 304 SS within the ranges of variable studied. However, the validity of the procedure is limited to the range of factors considered for the experimentation.

References

S. K. Majhi, M. K. Pradhan and H. Soni, (2013), Optimization of EDM parameters using integrated approach of RSM, GRA and ENTROPY method, *International Journal of Applied Research in Mechanical Engineering*, 3(1), pp 82-87.
A. Dvivedi, P. Kumar, and I. Singh, (2008) Experimental investigation and optimisation in EDM of Al 6063 SiCp metal matrix composite, *International Journal of Machining and Machinability of Materials*, 3(3 – 4), pp 293–308.
S. Assarzadeh and M. Ghoreishi, (2013), Statistical modeling and optimization of the EDM parameters on WC-6%Co composite through a hybrid response surface methodology-desirability function approach, *International Journal of Engineering Science and Technology*, 5 (6), pp 1279-1302.
M. K. Pradhan and C. K. Biswas, (2009), Modeling and Analysis of process parameters on Surface Roughness in EDM of AISI D2 tool Steel by RSM Approach, *International Journal of Engineering and Applied Sciences*, 5 (5), pp 246-351.
M. K. Pradhan and C. K. Biswas, (2008), Influence of process parameters on MRR in EDM of AISI D2 Steel: a RSM approach, *Proc. of the International conference on "Advances in Mechanical Engineering*, pp 872-877.
K. Wang, H. L. Gelgele, Y. Wang, Q. Yuan and M. Fang ,(2003) A hybrid intelligent method for modelling the EDM process, *International Journal of Machine Tools and Manufacture*, 43, pp 995–999
P. S. Rao, J. S. Kumar, K. V. K. Reddy and B. S. Reddy, (2010), Parametric study of electrical discharge machining of AISI 304 stainless steel *International Journal of Engineering Science and Technology*, 2 (8), pp 3535-3550.
R. Atefi, N. Javam, A. Razmavar and F. Teimoori, (2012), The Influence of EDM Parameters in Finishing Stage on Surface Quality, MRR and EWR, *Research Journal of Applied Sciences, Engineering and Technology*, 4(10), pp 1287-1294.
L. Li, L. Gu, X. Xi and W. Zhao, (2012), Influence of flushing on performance of EDM with bunched electrode, *Int J Adv Manuf Technol.*, 58, pp 187–194.
O. Yilmaz and M. A. Okka, (2010), Effect of single and multi-channel electrodes application on EDM fast hole drilling performance, *Int J Adv Manuf Technol.*, 51, pp 185–194.
M. Shabgard, M. Seyedzavvar, and S. N.B. Oliaei, (2011), Influence of Input Parameters on the Characteristics of the EDM Process, *Journal of Mechanical Engineering*, 57(9), pp 689-696.
K. Sandeep, (2013), Current Research Trends in Electrical Discharge Machining: A Review, *Res. J. Engineering Sci.*, 2(2), pp 56-60.
M. K. Pradhan and C. K. Biswas, (2008), Modelling of machining parameters for MRR in EDM using response surface methodology, *Proceedings of NCMSTA'08 Conference, National Institute of Technology*, Hamirpur, (India).
A. N Sait, S. Aravindan and A. N. Haq, (2009), Optimisation of machining parameters of glass-fibre-reinforced plastic (GFRP) pipes by desirability function analysis using Taguchi technique, *Int J Adv Manuf Technol.*, 43, pp 581–589.
S. Ravi, V. Balasubramanian, S. Babu and S. N. Nasser, (2004), Assessment of factors influencing the fatigue life of strength mis-matched HSLA steel weldments. *Mater. Des.* , 25, pp 125–135.
T. Barker, (1985), Quality by experimental design, New York: Marcel Dekker.
R. Lochner and J. Mater, (1990), Designing for quality, London: Chapman and Hall.
H. El-Hofy, (2005), Advanced machining processes, Egypt, McGraw-Hill.
M. K. Pradhan, (2010), Experimental investigation and modelling of surface integrity, accuracy and productivity aspects in EDM of AISI D2 steel. PhD thesis, National Institute of Technology, Rourkela (India).
P. S. Bharti, (2012), Optimization of process parameters of electric discharge machining based on Neural Networks and Taguchi's method, PhD thesis, Guru Gobind Singh Indraprastha University, Dwarka, Delhi.

Author Biography

Dr. Maan A. Tawfiq received his PhD in Production Engineering and Metallurgy at University of Technology, and currently is an assistant professor at this university. His research interests mainly include advanced manufacturing methods.

Saad Hameed Najem received his MSc in Production Engineering and Metallurgy at University of Technology, and currently is a PhD student at this university under supervision of Assistant Professor Maan A. Tawfiq. He is doing research in ED Machining.