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INVESTIGATION OF THE EFFECT OF PULSES CYCLE TIME AND ELECTRODE MATERIAL ON THE OVER CUT DURING THE ELECTRICAL DISCHARGE MACHINING PROCESS

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ABSTRACT

Through the Electrical Discharge Machining, temperature is very high, which affects material properties and process responses, and can lead to failure of the products in industry. This study aims to cover three points, firstly to investigate the effect of new input parameter (pulses cycle time Tc), with other parameters on the over cut (OC), the prediction model is developed. Second point assessing the effect of using Silver-Tungsten electrode and Cupper-Tungsten electrode on OC, during machining of powdered metallurgical high speed steel which is very important material in industry, such as aerospace, automotive, and electrical power industries, it is used in structural components, heat exchangers. Third point utilizing an integrated approach combines Response surface design and Genetic Algorithm optimization methodology for modeling and optimizing the response. Two software's Minitab software and Matlab software were utilized for this purpose. Experimental results demonstrated comparative findings when Silver-Tungsten electrode and Genetic Algorithms method were used. Optimized values of the responses were as following: optimized value of over cut was 0.049mm, optimization percentage was 30%.

Keywords: EDM process, Genetic Algorithm optimization, Over Cut (OC), powdered Metallurgical High Speed Steel (DEX20) and Silver-Tungsten electrode.

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1. INTRODUCTION

EDM is a controlled thermo electrical process, which there is spark generation between the cutting tool and work piece. There is no physical contact between work piece and the electrode. Many industries like aerospace, automobile, and casting molds have needed the EDM process to make many components. “The aerospace industry used EDM process to manufacture some aircraft parts because of the intricate shapes, tough alloys, and very tight tolerances involved, but it also recognized the dangers of the damaged surfaces and product defects resulting from the process” [1].

Although there are some Researchers made attempts to improve EDM performance, but as noticed from literature review that most researches focused on same ideas for optimization of process responses, input parameters, and even same workpiece materials.

Simultaneous optimization was made of the process performances like, metal removal rate, surface roughness and overcut based on Grey Taguchi methodology for machining of Ti-6A-4V Titanium alloy by EDM. The process parameters selected in this study are discharge current, open voltage, pulse duration and duty factor. The optimized process parameters simultaneously leading to a lower electrode wear ratio, higher material removal rate and better surface roughness, study show an improved electrode wear ratio of 15%, material removal rate of 12% and surface roughness of 19% when the Taguchi method and grey relational analysis are used [5].

Analytical study between the discharge energy parameters and the heat source characteristics are established in [3]. Also investigated the thermal properties of the discharged energy and their influence on material removal rate, gap distance, and surface roughness and recast layer. The experiments were conducted using copper electrode while varying discharge current and pulse duration. Analysis and experimental work conducted in this research allow selection of relevant parameters of discharge energy for the selection of best EDM machining conditions.

Author in [6] Applied Taguchi method and Grey Relational Analysis to improve the multi-response characteristics such as Material Removal Rate, Tool Wear Rate and Surface Roughness of mild steel IS 2026 during EDM process. It is found the optimal pulse current at 26A, pulse ON time at 55µs and pulse OFF time at 5µs.

Electrical discharge machining (EDM) of insulating ceramic materials, such as diamond was studied, using the assisting electrode method. This study investigated the dependence of the machining properties on amounts of additives, three types of insulating Si3N4 ceramics were machined by sinking EDM and by wire EDM. The material removal rate and the surface roughness were estimated on the EDMed workpiece. Different dependences on the amounts of added Al2O3 were observed, and the material removal rate depended on the size of the electrode [4]. Numerical approach was introduced to estimate material removal rate on work piece in EDM process. In this research, a thermo-physical finite element model for the simulation of single sparks machining was presented to analyze the process parameters and their effect on important responses like material removal rate on work piece Die steel, in electrical discharge machining (EDM) process and the model was solved by using ANSYS 16.0 software [2].

It is observed that likely no works has been reported on optimization of over cut during the EDM process for the material Powdered Metallurgical High Speed Steel, The present research deals with parametric optimization of the input process parameters during EDM of powdered metallurgical high speed steel. in this study Response surface methodology (Box Behnken) and genetic algorithm (GA) were integrated and utilized to optimize the input parameters and out response.

2. EXPERIMENTAL PROCEDURE AND DATA SET UP

The experiments conducted on EDM machine Model (CHARMILLES ROBOFORM 40).it is shown in Figure1

Figure 1 EDM machine

The task material in this study is Powdered High Speed Steel, its code is (DEX20) based on [7]. It is very important material in industry, it has not been investigated in the previous literature, it is HIP material (hot isostatic pressed) consolidated from very small powder particles. General Applications: cavity bar, trim form punches and dies, fine blanking, press die and punch for stainless steel, semiconductor tooling, cutting tool and etc, Figure 2 shows sample of DEX20 applications. Nearest equivalent Material is: (AISI M3-2).

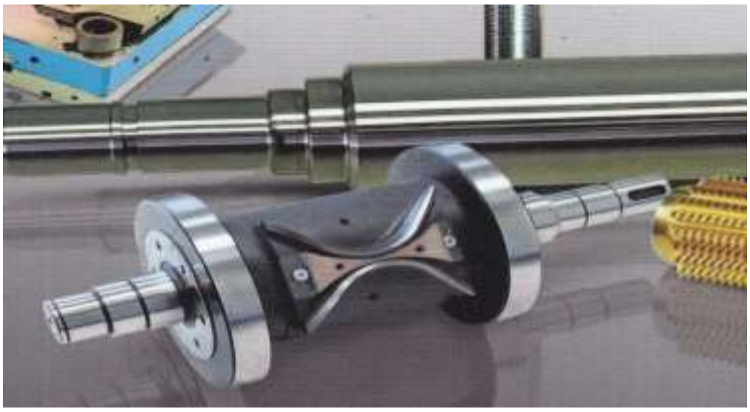

Figure 3 sample of DEX20 applications

Two types of electrode materials were used (copper-tungsten) electrode 100 mm long, diameter 20mm. And (silver-tungsten) electrode 100 mm long, diameter 20.70mm. The response will be investigated and optimized in this research is over cut:

Over Cut (OC): It is expressed as half the difference of diameter of the hole produced to the tool diameter that is shown in these equations:

$$OC = (Dh - Dt) / 2 \quad (1)$$

Whereas Dh = diameter of hole produced in the Workpiece

Dt = Diameter of tool, for Copper-Tungsten electrode is 20mm, for Silver-Tungsten electrode is 20.7mm

In this study Box-Behnken Experimental design Methodology was used to design the EDM process, L30 Orthogonal Array (OA), with (3) center points. Machining parameters are three continuous factors, and one category factor: pulses cycle time (Tc), dielectric fluid flushing pressure (P), and machining voltage (V), one Category factor (Type of electrode material), machining parameter and their levels are presented in Table 1.

Fixed parameters: current 6A, Pulse width 200 µs, polarity of electrode is positive.

Dielectric: hydrocarbon fluid for universal application in EDM operations with properties density of 0,783 g/ml, flash point of 125 ºC.

Table 1 Machining parameter and their levels

Parameters	**Symbol**	**Levels**			**Unit**
		1	2	3	
Period of machining (pulses cycle time)	Tc	0.1	6.4	12.8	sec
Dielectric Fluid Flushing Pressure	P	5	15	25	Psi
Machining Voltage	V	120	160	200	v
Electrode material	Cu-W Copper-Tungsten		Ag-W Silver-Tungsten		

Genetic algorithms (GA) optimization begins with a set of solutions represented by chromosomes, called population. Solutions from one population are taken and used to form a new population, which is motivated by the possibility that the new population will be better than the old one [8].

Further, solutions are selected according to their fitness to form new solutions. The above process is repeated until some condition is satisfied. In the present study, GA will be used as an optimization technique for solving a bound-constrained optimization problem. The models developed by the (box – Behnken) optimization methodology will be used as objective function and the upper and lower bounds of parameters are identified by conducting experiments.

The main aim is to maximize the Response value.

So, the objective functions: Minimize Z = W×Response for Responses to be min. is better.

W is arbitrarily chosen parameters to represent the importance of each response parameter and taken as 1.

Subjected to,

$120 \leq V \leq 200$;

$0.1 \leq Tc \leq 12.8$;

$5 \leq P \leq 25$.

All the previous steps for optimization process were carried out in GA Tool box of Matlab software.

3. RESULT ANALYSIS AND DISCUSSION

In this section the results and their analyses are discussed for response variable. Then a regression analysis was conducted to find the best-fit models. The main effects and the interaction effects were discussed.

Tables 2 and 3 show the Experimental results for work piece (DEX20) with two types of tools, Copper-Tungsten (Cu-W), Silver-Tungsten (Ag-W), and using Response Surface Design Methodology (Box-Behnken).

Table 2 Results of OC, using Box-Behnken Design, electrode (Cu-W)

Run Order	V volt	Tc Sec	P Psi	Electrode Material	OC (mm)
1	200	0.10	15	Cu-W	0.155
2	120	0.10	15	Cu-W	0.14
3	120	6.45	5	Cu-W	0.12
4	120	6.45	25	Cu-W	0.125
5	120	12.80	15	Cu-W	0.17
6	160	0.10	5	Cu-W	0.16
7	200	6.45	25	Cu-W	0.17
8	200	12.80	15	Cu-W	0.195
9	160	6.45	15	Cu-W	0.16
10	160	12.80	25	Cu-W	0.225
11	160	12.80	5	Cu-W	0.105
12	160	6.45	15	Cu-W	0.16
13	160	6.45	15	Cu-W	0.13
14	160	0.10	25	Cu-W	0.12
15	200	6.45	5	Cu-W	0.125

Table 3 Results of OC using Box-Behnken Design, electrode (Ag-W)

Run Order	V Volt	Tc sec	P	Electrode Material	OC (mm)
16	160	0.10	5	Ag-W	0.100
17	120	6.45	25	Ag-W	0.175
18	120	6.45	5	Ag-W	0.070
19	160	6.45	15	Ag-W	0.150
20	160	12.80	25	Ag-W	0.200
21	160	12.80	5	Ag-W	0.090
22	160	6.45	15	Ag-W	0.125
23	160	0.10	25	Ag-W	0.195
24	120	12.80	15	Ag-W	0.100
25	200	6.45	5	Ag-W	0.135
26	200	12.80	15	Ag-W	0.160
27	120	0.10	15	Ag-W	0.120
28	200	0.10	15	Ag-W	0.165
29	160	6.45	15	Ag-W	0.170
30	200	6.45	25	Ag-W	0.170

ANOVA is used to check the second-order models, which includes test for significance of the fitted models, parameters significance, and test for lack-of-fit. Also check R^2, R^2 (adjusted), R^2 (predicted). The analysis of variance (ANOVA) based on the resulting data is shown in tables 4 and 5. The tables include the sources of variation, degrees of freedom (DF), and the sum of squares (SS), contribution of the sources in the variation, the mean squares (MS), F-values, and p-values. In this analysis, a p-value that was lower than 0.05 was statistically significant. Main and interaction effects are shown in figures 3-6.

3.1. Effect of Process Parameters on Over Cut, using (Cu-W) Electrode

Over cut was calculated by measuring the difference in radius of the machined hole before and after machining, results are shown in tables 2.

Full quadratic second order model is used and considered for the analysis and study the effect of the parameters on the response (OC), in this analysis, a p-value that was lower than 0.1 was statistically significant.

Table 4 Analysis of Variance of OC, Workpiece (DEX20), using (Cu-W) electrode

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.013568	0.001508	9.73	0.011
Linear	3	0.004925	0.001642	10.59	0.013
V	1	0.001013	0.001013	6.53	0.051
Tc	1	0.001800	0.001800	11.61	0.019
P	1	0.002113	0.002113	13.63	0.014
Square	3	0.001818	0.000606	3.91	0.088
V*V	1	0.000006	0.000006	0.04	0.855
Tc*Tc	1	0.000975	0.000975	6.29	0.054
P*P	1	0.000698	0.000698	4.50	0.087
2-Way Interaction	3	0.006825	0.002275	14.68	0.007
V*Tc	1	0.000025	0.000025	0.16	0.705
V*P	1	0.000400	0.000400	2.58	0.169
Tc*P	1	0.006400	0.006400	41.29	0.001
Error	5	0.000775	0.000155		
Lack-of-Fit	3	0.000175	0.000058	0.19	0.893
Pure Error	2	0.000600	0.000300		
Total	14	0.014343			
S: 0.0124499	R-sq: 94.60%	R-sq(adj): 84.87%	R-sq(pred): 71.07%		

3.1.1. Statistical inferences

1. The Model is significant, P-Value is 0.011, that is mean the Model is significant and adequate.
2. The "Lack of Fit of 0.893 implies the Lack of Fit is not significant relative to the pure error. Non-significant lack of fit is good.
3. The “R-Squared" of 94.60%, "Pred R-Squared" of 71.07% is in reasonable agreement with the "Adj R-Squared" of 84.87%. This model can be used to navigate the design space and indicates an adequate signal.
4. Values of “Prob. less than 0.1” indicate model terms are significant. In this case V, Tc, P, (P*P), (Tc*Tc), (Tc*P) are significant model terms.

3.1.2. Regression Equation of OC

OC = 0.162 + 0.00009 V - 0.01386 Tc - 0.00231 P - 0.000001 V*V + 0.000403 Tc*Tc - 0.000138 P*P + 0.000010 V*Tc + 0.000025 V*P + 0.000630 Tc*P

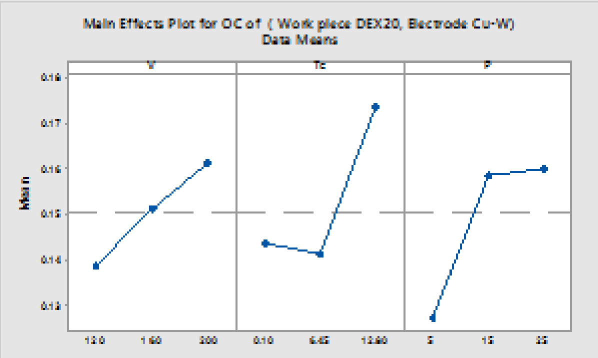

Figure 3 The main effects plot for OC, Workpiece (DEX20), and using (Cu-W) electrode

The main effects: Figure 3 displays the main effects plot for OC. Based on this plot, as Tc pulse cycles time increase as OC decrease until 6.45s then OC increases. Increasing Voltage resulted in increasing of OC. Dielectric liquid pressure as increased as OC increased. The maximum over cut was at pressure 25 psi.

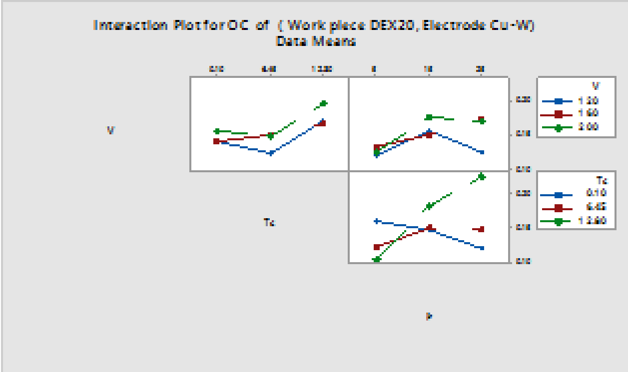

Figure 4 The interaction effects plot for OC, Workpiece (DEX20), and using (Cu-W) electrode

The interaction effect: Figure 4 displays the interaction effects plots for OC. Based on the ANOVA Table 4, the interactions that their p-value was less than 0.1 of is (Tc*P), this interaction effect was significant.

3.2. Effect of Process Parameters on Over Cut, using (Ag-W) Electrode

Second order model is used and considered for the analysis and study the effect of the parameters on the response (OC), in this analysis, a p-value that was lower than 0.1 was statistically significant.

Table 5 Analysis of Variance of OC, Workpiece (DEX20), used electrode (Ag -W)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	6	0.019731	0.003289	11.68	0.001
Linear	3	0.018394	0.006131	21.78	0.000
V	1	0.003403	0.003403	12.09	0.008
Tc	1	0.000112	0.000112	0.40	0.545
P	1	0.014878	0.014878	52.85	0.000
2-Way Interaction	3	0.001338	0.000446	1.58	0.268
V*Tc	1	0.000056	0.000056	0.20	0.667
V*P	1	0.001225	0.001225	4.35	0.070
Tc*P	1	0.000056	0.000056	0.20	0.667
Error	8	0.002252	0.000282		
Lack-of-Fit	6	0.001235	0.000206	0.41	0.835
Pure Error	2	0.001017	0.000508		
Total	14	0.021983			
S R-sq R-sq(adj) R-sq(pred) 0.016778 89.76% 82.07% 67.30%					

3.2.1. Statistical inferences

1. The Model is significant, **P-Value** is 0.001, that is mean the Model is significant and adequate.
2. The "Lack of Fit of 0.835 implies the Lack of Fit is not significant relative to the pure error. Non-significant lack of fit is good.

3. The “R-Squared" of 89.76%, "Pred R-Squared" of 67.30% is in reasonable agreement with the "Adj R-Squared" of 82.07%. This model can be used to navigate the design space and indicates an adequate signal.
4. Values of “Prob. less than 0.1” indicate model terms are significant. In this case V, P, (V*P) are significant model terms.

3.2.2. Regression Equation of OC

OC = -0.0858 + 0.001077 V - 0.00384 Tc + 0.01093 P + 0.000015 V*Tc - 0.000044 V*P + 0.000059 Tc*P

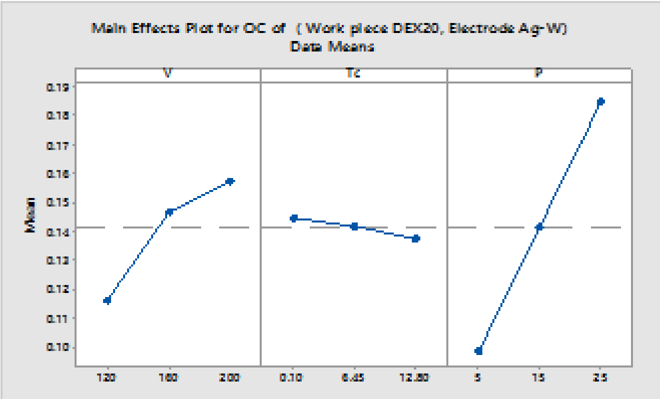

Figure 5 The main effects plot for OC, Workpiece (DEX20), used electrode (Ag -W)

The main effects: Figure 5 displays the main effects plot for OC. Based on this plot, as the parameters V, P increased as over cut increases, and almost not affected with change of Tc.

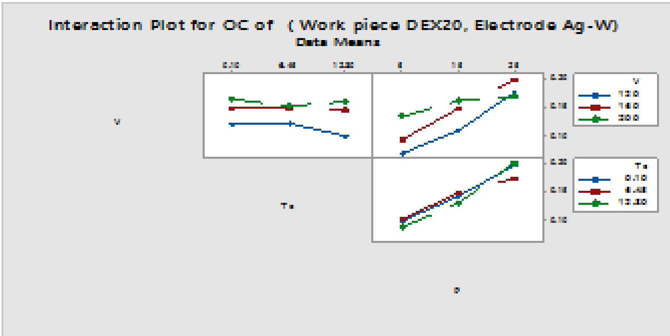

Figure 6 the interaction effects plot for OC, Workpiece (DEX20), used electrode (Ag -W)

The interaction effect: Figure 6 displays the interaction effects plots for OC. Based on the ANOVA Table, the interaction that its p-value was less than 0.1 is (V*P), these interactions effect was significant.

4. OPTIMIZATION OF THE OVER CUT USING GENETIC ALGORITHM METHODOLOGY

The obtained response equations will be used as objective function

Subjected to:

$120 \leq V \leq 200$;

$0.1 \leq Tc \leq 12.8$;

$5 \leq P \leq 25$;

Cu-W = Tool Material = Ag-W.

The optimization is carried out in GA Tool box of MATLAB (Version: 8.5.0.197613). The equations variables and parameters are coded to be accepted formula in Genetic Algorithm Tool in the Matlab Software:

Response = f(x)

V= X1, Tc=X2, P=X3, Maximum and minimum boundary conditions are [120, 0.1, 5] and [200, 12.8, 25].

Tables 6-7 and Figures 7-8 show the optimization results of both Cu-W and Ag-W electrodes.

4.1. Optimization of OC, used electrode (Cu-W)

After achieving and building the equation models from response surface design (Box–Behnken) methodology, they will be used as objective function equation in GA optimization:

4.1.1. Response surface equation

OC = 0.162 + 0.00009 V - 0.01386 Tc - 0.00231 P - 0.000001 V*V + 0.000403 Tc*Tc - 0.000138 P*P + 0.000010 V*Tc + 0.000025 V*P + 0.000630 Tc*P

This equation transferred to genetic algorithm program code to be as following:

4.1.2. Coding equation (minimization:

f(4) = 0.162 + 0.00009*x(1) - 0.01386*x(2) - 0.00231*x(3) - 0.000001*(x(1)^2) + 0.000403*(x(2)^2) - 0.000138*(x(3)^2) + 0.000010*(x(1)*x(2)) + 0.000025 *(x(1)*x(3)) + 0.000630*(x(2)*x(3));

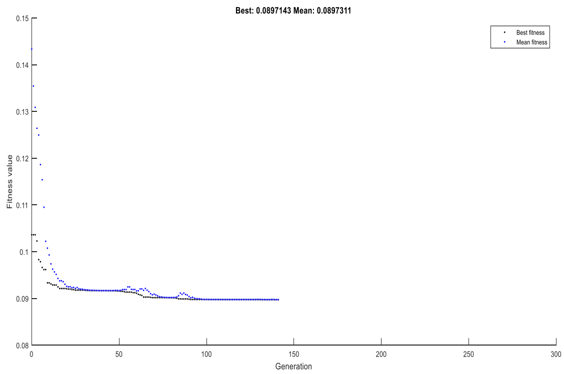

Figure 7 Plot of fitness value with number of generation of OC, used electrode Cu-W

Table 6 The optimum values of process parameters of OC, used electrode Cu-W

Response	Optimize value of input parameters			Value	Iteration Number
	V	Tc	P		
OC	120	0.1	25	Objective function value: 0.0897	141

4.2. Optimization of OC, used electrode (Ag-W)

4.2.1. Response surface equation

OC = -0.0858 + 0.001077 V - 0.00384 Tc + 0.01093 P + 0.000015 V*Tc - 0.000044 V*P + 0.000059 Tc*P

This equation transferred to genetic algorithm program code to be as following:

4.2.2. Coding equation (minimization:

f(4) = -0.0858 + 0.001077*x(1) - 0.00384*x(2) + 0.01093*x(3) + 0.000015*(x(1)*x(2)) - 0.000044 *(x(1)*x(3)) + 0.000059 *(x(2)*x(3));

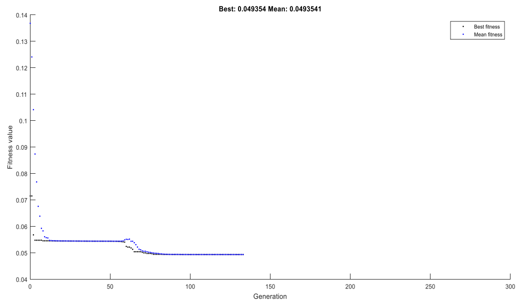

Figure 8 Plot of fitness value with number of generation of OC, for Material DEX20, Electrode Ag-w

Table 7 the optimum values of process parameters of OC, for Material DEX20, Electrode Ag-w

Response	Optimize value of input parameters			Response Value (mm)	Iteration Number
	V	Tc	P	Objective function value: 0.0493	133
OC	120	12.799	5		

4.3. Best Optimum Selected Results using Genetic Algorithm Methodology

Comparing of the optimum results for both types of electrodes, (Cu-W) and (Ag-W) using Genetic Algorithm optimization methodology, table 8 shows the chosen best optimum results between the two electrodes.

Table 8 The best selected optimum results of OC, Material DEX20 using Genetic Algorithm

Optimum values	Response OC	Voltage (V)	Pulse Cycle Time (Tc)	Pressure (P)	Electrode Material
	0.0493	120.0	12.799	5.0	Ag-W

5. CONCLUSION

a. The summary of optimal result of over cut for DEX20 material with electrode Cu-W, It is found that P is the most dominating parameter followed by Tc and V, model is significant where R^2 94.60% and Lack of Fit 0.893**.** Minimum Value of OC as predicted from experiments was 0.105 mm. Optimized value using Genetic Algorithm methodology is 0.0897 mm, when the applied machining conditions are: V=120v, Tc=0.1s, P= 25psi. Optimization percentage using GA is 15.23%.

b. The optimal results with electrode Ag-W, It is found that P is the most dominating parameter followed by V. Tc is not significant; model is significant, where R^2 89.76% and Lack of Fit 0.835**.** Minimum Value of OC as predicted from experiments was 0.070 mm. Optimized value using Genetic Algorithm methodology is 0.049mm, when the applied machining conditions are: V=120v, Tc=12.8s, P= 5psi, optimization percentage using GA is 30%.

Based on result analysis and optimization, results revealed that optimum results were achieved, when Genetic Algorithm optimization methodology are used. So using the integrated methodology between Response Surface Design Method (Box Behnken) and Genetic Algorithm Optimization is considered as effective Tool.

REFERENCES

[1] Aerospace Manufacturing, EDM for Aerospace, Aerospace Production, Radical Departures. Retrieved from https://www.radical-departures.net/articles/advances-in-edm-for-aerospace' (2018).

[2] Gosavi, A. and Gaikwad, A. B. Predicting Optimized EDM Machining Parameter through Thermo Mechanical Analysis, *IOSR Journal of Mechanical and Civil Engineering*, 13(3), (2016), pp. 2320–334. doi: 10.9790/1684-1303057185.

[3] Gostimirovic, M. *et al.* Influence of discharge energy on machining characteristics in EDM, *Journal of Mechanical Science and Technology*, (2012). doi: 10.1007/s12206-011-0922-x.

[4] Hanaoka, D. *et al.* Discharge Machining of Insulating Si3N4 Ceramics with added Al2O3', *International Journal of Electrical Machining*, 19, (2014), pp. 45–50. doi: 10.2526/ijem.19.45.

[5] Kao, J. Y. *et al.* Optimization of the EDM parameters on machining Ti-6Al-4V with multiple quality characteristics, *International Journal of Advanced Manufacturing Technology*, (2010). doi: 10.1007/s00170-009-2208-3.

[6] Raghuraman, S. *et al.* Optimization of Edm Parameters Using Taguchi Method and Grey Relational Analysis for Mild Steel Is 2026, *International Journal of Innovative Research in Science, Engineering and Technology*, 2(7), (2013), pp. 3095–3104.

[7] Special steel and alliance. (2013), Available at: http://www.specialsteel.com.my/page.php?page=powder.

[8] Ab Wahab, M. N., Nefti-Meziani, S. and Atyabi, A. A comprehensive review of swarm optimization algorithms , 10(5), (2015), pp. 1–36. doi: 10.1371/journal.pone.0122827.