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Experimental Investigation and Optimization of RaValue, EWR, and MRRinElectric DischargeMachining

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Abstract:*The objective of research is to study the influence of process parameters and electrode shape configuration on the machining characteristics of die sinking EDM. The present work aims to study the effect of circular electrode shape with constant cross sectional area and having 8.462 g weight on material removal rate (MRR), surface roughness (Ra) and electrode wear rate (EWR) for AISI 316 stainless steel workpiece material and graphite as electrode material.*

The experimentations performed by operating on Electric Discharge Machine classified as Electronica-Electra plus Ps 50 Znc whose polarization on the electrode be located as negative whereas that of work piece is located as positive. The dielectric liquid recycled was EDM oil having specific gravity - 0.763. The optimization of the parameters of the EDM machining will be carried out by using the taguchi (L_9 – Orthogonal Array) method.

At last the results shown and conclude that the roughness value, electrode wear rate, and material removal rate after machining are compared with estimated values. The correlation would be able to predict the estimated roughness value by accuracy 99.51%, 97.27% accuracy for electrode wear rate, and 64.68% accuracy for material removal rate.

Keywords: *EDM, AISI 316 Stainless Steel, Graphite Electrode, Taguchi, Regression.*

I. Introduction

The new concept of manufacturing uses non-conventional energy sources like sound, light, mechanical, chemical, electrical, electrons and ions*[1, 2]*. With the industrial and technological growth, development of harder and difficult to machine materials, which find wide application in aerospace, nuclear engineering and other industries owing to their high strength to weight ratio, hardness and heat resistance qualities has been witnessed*[3, 6, 8]*. New developments in the field of material science have led to new engineering metallic materials, composite materials and high tech ceramics having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by spark erosion*[4, 5]*.

Non-traditional machining has grown out of the need to machine these exotic materials. The machining processes are non-traditional in the sense that they do not employ traditional tools for metal removal and instead they directly use other forms of energy*[9, 13]*. The problems of high complexity in shape, size and higher demand for product accuracy and surface finish can be solved through non-traditional methods*[10, 11, 12]*. Currently, non-traditional processes possess virtually unlimited capabilities except for volumetric material removal rates, for which great advances have been made in the past few years to increase the material removal rates. As removal rate increases, the cost effectiveness of operations also increase, stimulating ever greater uses of non-traditional process *[14]*.

- **Electric Discharge Machining (EDM)**

Electro Discharge Machining (EDM) is an electro-thermal non-traditional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark. EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. EDM can be used to machine difficult geometries in small batches or even on job-shop basis. Work material to be machined by EDM has to be electrically conductive*[15]*.

- **Principle of EDM**

The process has been explained by different theories, being the thermo-electric model the one that best fits the practical experiments*[16]*. The charge loaded electrode approaches the surface of the component, which is loaded with the opposite charge. In between both electrodes there is an isolating fluid, referred as dielectric fluid*[18]*. Despite being an electric insulator, a large voltage difference can produce the dielectric breakage, producing ionic fragments that make possible the electric current to jump between the electrode and the work piece*[17]*. The presence of metallic particles suspended in the dielectric fluid can be good for the electricity transfer in two different 8 ways: on one side, the particles are good to ionise the dielectric and, what is more, they can provide the electric charge; on the other side, the particles can catalyse the dielectric breakage. For that reason, the electric field is larger in that position in which the electrode and the work piece are closer*[19]*.

II. Experimentations

The machine is used for this experimentation ELECTRONICA-ELECTRAPLUS PS 50 ZNC with servo head (constant gap). EDM oil is used as dielectric fluid specific gravity= 0.763, freezing point= 94°C. The experimentations be there performed by operating on Electric Discharge Machine classified as ELECTRONICA-ELECTRAPLUS PS 50 ZNC whose polarization on the electrode be located as negative whereas that of work piece be located as positive. The dielectric liquid recycled was EDM oil having specific gravity - 0.763. The EDM machine contains with the following measures:

- For circulation of dielectric there is reservoir at base, pump and valves for passage.
- Power supply unit and CNC functions.
- Leak-proof tank along with tool fixing chuck.
- Two dimension movable table by lever.
- Tool holding device.
- Servo control unit for vertical movement of the tool.

2.1AISI 316 Stainless Steel as Workpiece Material

AISI 316 grade austenitic stainless steel,it contains 16% to 18% chromium and 11% to 14% nickel. AISI 316 stainless steel has molybdenum added to the nickel and chrome of the 304. AISI 316 stainless steel has molybdenum, which gives it more corrosion resistance. Type 316 stainless steel is often used in heavy gauge welding applications because the risk of pitting, cracking and corrosion is reduced. Grade 316 is the standard molybdenum bearing grade. Molybdenum gives 316 better overall corrosion resistant properties than grade 304. It has excellent forming and welding characteristics. It is readily brake or roll formed into a variety of parts. Material for use in sea-water, equipment for manufacturing dye, paper, acetic acid, fertilizer and chemicals, in the photo industry, food industry, the facilities constructed in the coastal area, bolts and nuts*[20, 23]*.

Stainless steel 316 Low carbon alloy is selected. Grade 316 has excellent corrosion resistance in a wide range of media. Its main advantage over grade 304 is its increased ability to resist pitting and crevice corrosion in warm chloride environments*[21]*. It resists ordinary rusting in virtually all architectural applications, and is often chosen for more aggressive environments such as sea-front buildings and fittings on wharves and piers*[22]*. Like grade 304, 316 have good oxidation resistance in intermittent service to 870ºC and in continuous service to 925ºC*[24]*. Like other austenitic stainless steels, grade 316 has excellent forming characteristics. It can be deep drawn without intermediate heat softening enabling it to be used in the manufacture of drawn stainless parts, such as sinks and saucepans. The below table 1show the chemical composition and mechanical properties of AISI 316 stainless steel*[25]*.

Table 1: Composition of different elements present in AISI 316*[27]*

Elements	C	Mn	Si	P	S	Cr	Mo	Ni	N
Weight %	0.08	2	0.75	0.045	0.03	18	3	14	0.10

Table 2: Mechanical properties of AISI 316 grade stainless steels*[26]*

Tensile strength (MPa)	Yield stress (MPa)	Rockwell hardness (HRB)	Brinell hardness (BHN)
515	205	95	217

2.2 Difference and advantages of 316 over 304 stainless steel

Type 304 is the most common austenitic grades, containing normally, 20% chromium and 10% nickel, combined with a maximum of 0.08 % carbon. While type 316 contains 16% to 18% chromium and 11% to 14% nickel. AISI 316 stainless steel has molybdenum added to the nickel and chrome of the 304. Carbon contain is 0.03 %.The main difference is that 316 contain 2% - 3% molybdenum and 304 have no molybdenum.The "moly" is added to improve the corrosion resistance to chlorides*[27, 28]*.AISI 304 stainless steel is used for chemical possessing equipment, for food, for dairy, for heat exchangers,and for the milder chemicals. While Type 316 is used in chemical processing, in the pulp andpaper industry, for food and beverage processing and dispensing.In the marine environment, where strength and wearresistance are needed, and type 304being slightly higher strength and wear resistance than type 316 it is used for nuts, bolts andscrews*[29, 30]*.

Type 316 stainless steel has molybdenum, which gives it more corrosion resistance than the type304 stainless steel. In chlorine environment, AISI 316 stainless steel offers a high resistance tocrevice corrosion and pitting than the 304 stainless steel.AISI 316 stainless steel is often used in heavy gauge welding applications because the risk ofpitting, cracking and corrosion is reduced, while type 304 stainless steel often used in thecreation of cookware and in the construction of dairy equipment, such as milking machines.

2.3 Graphite as Electrode Material

A special grade for EDM is made available in this material. It is the second best choice for Electrode making. It can be easily machined The material being brittle is not recommended for making electrode of small sizes, shapes, but can be easily used where cavity sizes are large. It is not recommended for Tungsten Carbide job. The circular shape electrodeis used in the machining process and the dimensions of the electrodes are taken standard.

2.4 Experimental Taguchi Design

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L_9 orthogonal array (OA) design have been selected. In the present experimental study, spindle speed, feed rate and depth of cut have been considered as process variables. The process variables with their units (and notations) are listed in table 2.

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L_9 (3^3) orthogonal array (OA) design have been selected. In the present experimental work, Current (A), Pulse on Time (s), and Gap Voltage (V) have been considered asmachining parameters. The machining parameters and their associated ranges are given in the table 3. Taguchi design concept, for three levels and three parameters, nine experiments are to be performed and hence L_9 orthogonal array has selected.

Table 3: Process variables and their limits

FACTORS	LEVEL 1	LEVEL 2	LEVEL 3
Current (A)	10	15	20
Pulse on Time (s)	200	250	300
Gap voltage (V)	40	50	60

The L_9 orthogonal array of taguchi experiment design sequence results is revealed in below table 4:

Table 4: L_9 orthogonal array taguchi experiment design

Run No.	Cutting parameters level by Taguchi method		
	A	s	V
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The L_9 orthogonal array of taguchi experiment design sequence and the actual reading results is revealed in below table 5:

Table 5: L_9 orthogonal array taguchi experiment design with actual 9 runs

Run No.	Cutting parameters level by Taguchi method			Actual Cutting parameters level by Taguchi method		
	A	s	V	A	s	V
1	1	1	1	10	200	40
2	1	2	2	10	250	50
3	1	3	3	10	300	60
4	2	1	2	15	200	50
5	2	2	3	15	250	60
6	2	3	1	15	300	40
7	3	1	3	20	200	60
8	3	2	1	20	250	40
9	3	3	2	20	300	50

III. Modelling

The modeling has done by the regression analysis software, the regression analysis done by the Minitab software. The regression analysis done through the software to estimate the new value of roughness from the regression analysis derived formula. At last the absolute error and the percentage error calculated. The modeling of roughness value from Current, Pulse on Time, and Gap Voltage has given in table 6.

Table 6: Observation table of modeling of roughness value from current, pulse on time, and gap voltage

Sr. No.	By Taguchi Method			Actual Values			Exp. Ra in µm	Est. Ra in µm	Absolute Error
	A	s	V	A	s	V			
1	1	1	1	10	200	40	6.6673	6.6717	-0.0044
2	1	2	2	10	250	50	7.8941	7.9185	-0.0244
3	1	3	3	10	300	60	9.1209	9.1653	-0.0444
4	2	1	2	15	200	50	7.0687	7.0465	0.0222
5	2	2	3	15	250	60	8.2955	8.2933	0.0022
6	2	3	1	15	300	40	7.0900	6.9678	0.1222
7	3	1	3	20	200	60	7.4702	7.4213	0.0489
8	3	2	1	20	250	40	5.9846	6.0957	-0.1111
9	3	3	2	20	300	50	7.3315	7.3426	-0.0111

Regression Equation

$$Ra_{(Est.)} = 2.64978 - 0.0965334\,A + 0.00778734\,s + 0.085745\,V \qquad \text{...(Eq. 1)}$$

Table 7: Regression analysis table for roughness value calculations

Coefficients				
Term	Coef	SE Coef	T	P
Constant	2.64978	0.255758	10.3605	0.000
A	-0.09653	0.006622	-14.5775	0.000
S	0.00779	0.000662	11.7597	0.000
V	0.08574	0.003311	25.8967	0.000

Summery Model		
S = 0.0811035	R – Sq = 99.51 %	R – Sq (Adj) = 99.22 %
Press = 0.119898	R – Sq (Pred) = 98.22 %	

Analysis of Variance						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3	6.81876	6.71876	2.23959	340.478	0.0000034
A	1	1.39780	1.39780	1.39780	212.504	0.0000274
s	1	0.90964	0.90964	0.90964	138.290	0.0000782
V	1	4.41132	4.41132	4.41132	670.640	0.0000016
Error	5	0.03289	0.03289	0.00658		
Total	8	6.75165				

Fits and Diagnostics for Unusual Observations						
Obs	Ra	Fit	SE Fit	Residual	St Resid	
6	7.09000	6.96778	0.0540690	0.122222	2.02184	R

R denotes an observation with a large standardized residual.

From the above analysis it has been seen that, the R^2 value shows the speed, feed, and depth of cut explains 99.51% of the variance in roughness value, indicating that the model fits the data extremely well which means that current, pulse on time, and gap voltage explanatory power in roughness value is 99.51%. 0.49% is unexplained variance.

3.1 Electrode Wear Rate (EWR):

The electrode wear rate can be calculated as by taking the difference between the weights of before machining and after machining and divide these differences by the time, which is taken for actual machining. Table show the information about the electrode wear rate.

Table 8: Electrode Wear Rate calculations

Sr. No.	By Taguchi Method			Actual Values			Exp. EWR in g/min	Est. EWR in g/min	Absolute Error
	A	s	V	A	s	V			
1	1	1	1	10	200	40	0.00180	0.0026	-0.0008
2	1	2	2	10	250	50	0.00312	0.0033	-0.0002
3	1	3	3	10	300	60	0.00440	0.0040	0.0004
4	2	1	2	15	200	50	0.0090	0.0085	0.0005
5	2	2	3	15	250	60	0.00888	0.0092	-0.0003
6	2	3	1	15	300	40	0.00880	0.0077	0.0011
7	3	1	3	20	200	60	0.01470	0.0143	0.0004
8	3	2	1	20	250	40	0.01320	0.0129	0.0003
9	3	3	2	20	300	50	0.01220	0.0136	-0.0014

Regression Equation

$$EWR_{(Est.)} = -0.0103344 + 0.001026\,A - 3.33333x10^{-7}\,s + 6.96667 \times 10^{-5}\,V \qquad ...(Eq.\ 2)$$

Table 9: Regression analysis table for Electrode Wear Rate calculations

Coefficients

Term	Coef	SE Coef	T	P
Constant	-0.0103344	0.0029969	-3.4483	0.018
A	0.0010260	0.0000776	13.2223	0.000
s	-0.0000003	0.0000078	-0.0430	0.967
V	0.0000697	0.0000388	1.7956	0.133

Summery Model

S = 0.000950357	R – Sq = 97.27 %	R – Sq (Adj) = 95.63 %
Press = 0.0000175874	R – Sq (Pred) = 89.36 %	

Analysis of Variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3	0.0001608	0.0001608	0.0000536	59.352	0.000249
A	1	0.0001579	0.0001579	0.0001579	174.829	0.000044
s	1	0.0000000	0.0000000	0.0000000	0.002	0.967398
V	1	0.0000029	0.0000029	0.0000029	3.224	0.132503
Error	5	0.0000045	0.0000045	0.0000009		
Total	8	0.0001653				

Fits and Diagnostics for Unusual Observations

Obs	Ra	Fit	SE Fit	Residual	St Resid
No unusual observations.					

From the above analysis it has been seen that, the R^2 value shows the speed, feed, and depth of cut explains 97.27% of the variance in roughness value, indicating that the model fits the data extremely well which means that current, pulse on time, and gap voltage explanatory power in roughness value is 97.27%. 2.73% is unexplained variance.

3.2 Material Removal Rate (MRR)

The material removal rate can be calculated as by taking the difference between the weights of before machining and after machining and divide these differences by the time and density, which is taken for actual machining. Table show the information about the material removal rate.

Table 10: Material Removal Rate calculations

Sr. No.	By Taguchi Method			Actual Values			Exp. MRR (mm^3/min)	Est. MRR(mm^3/min)	Absolute Error
	A	s	V	A	s	V			
1	1	1	1	10	200	40	41.53247	44.59807	-3.06560
2	1	2	2	10	250	50	37.83117	39.81019	-1.97902
3	1	3	3	10	300	60	32.44156	35.02231	-2.58075
4	2	1	2	15	200	50	45.35065	39.42706	5.923595
5	2	2	3	15	250	60	35.37662	34.63917	0.737447
6	2	3	1	15	300	40	37.84416	29.25389	8.590268
7	3	1	3	20	200	60	35.22078	34.25604	0.964742
8	3	2	1	20	250	40	22.46753	28.87076	-6.40323
9	3	3	2	20	300	50	21.89610	24.08288	-2.18678

Regression Equation

$$MRR_{(Est.)} = 74.4899 - 1.07403\,A - 0.0997403\,s + 0.0199133\,V \qquad ...(Eq.\ 3)$$

Table 11: Regression analysis table for Material Removal Rate Calculations

Coefficients

Term	Coef	SE Coef	T	P
Constant	74.4899	18.7155	3.98011	0.011
A	-1.0740	0.4846	-2.21640	0.077
s	-0.0997	0.0485	-2.05828	0.095
V	0.0199	0.2423	0.08219	0.938

Summery Model

S = 5.93488	R – Sq = 64.68 %	R – Sq (Adj) = 43.49 %
Press = 575.586	R – Sq (Pred) = -15.44 %	

Analysis of Variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3	322.490	322.490	107.497	3.05190	0.130454
A	1	173.030	173.030	173.030	4.91243	0.077478
s	1	149.222	149.222	149.222	4.23651	0.094640

V	1	0.238	0.238	0.238	0.00675	0.937686
Error	5	176.114	176.114	35.223		
Total	8	498.604				

Fits and Diagnostics for Unusual Observations

Obs	Ra	Fit	SE Fit	Residual	St Resid
No unusual observations.					

From the above analysis it has been seen that, the R^2 value shows the speed, feed, and depth of cut explains 64.68% of the variance in roughness value, indicating that the model fits the data extremely well which means that current, pulse on time, and gap voltage explanatory power in roughness value is 64.68%. 35.32% is unexplained variance.

IV. Results And Discussion

As the modeling done through the modeling software, the various statistical correlations formed from the analysis by Minitab software version 16. The various correlations formed and which are having machining parameters relation with roughness value, electrode wear rate, and material removal rate.
The correlations developed from the statistical analyses, which are given below:

$$Ra_{(Est.)} = 2.64978 - 0.0965334\ A + 0.00778734\ s + 0.085745\ V \quad ...(Eq.\ 1)$$

$$EWR_{(Est.)} = -0.0103344 + 0.001026\ A - 3.33333x10^{-7}\ s + 6.96667\ x\ 10^{-5}\ V \quad ...(Eq.\ 2)$$

$$MRR_{(Est.)} = 74.4899 - 1.07403\ A - 0.0997403\ s + 0.0199133\ V \quad ...(Eq.\ 3)$$

4.1 Correlation between Estimated Roughness value and Experimental Roughness Value

The below given graphical representation 1 show the correlation between the experimental roughness value and the estimated roughness value. The experimental roughness value is the actual roughness value measured by the roughness tester and the estimated roughness values are the values, which are estimated from the regression equation and the main factors current, pulse on time, gap voltage have considered. This is the final regression equation which shows the strongest correlation between machining parameters and the correlation gives R^2 value 99.51 %. The below given figure 1 show the correlation between experimental and estimated roughness value.

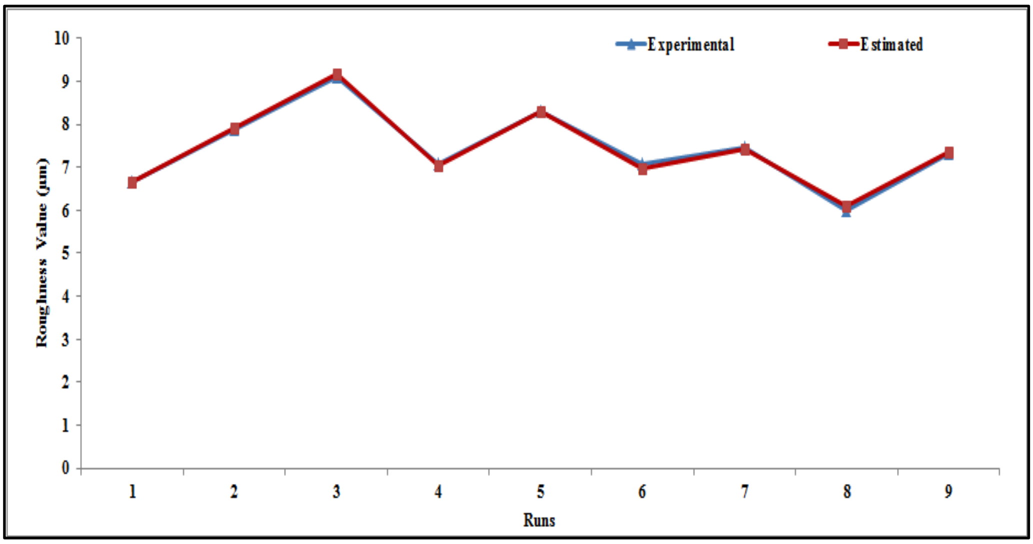

Figure 1: Estimated and Experimental Roughness Values versus Runs

4.2 Correlation between Estimated Electrode Wear Rate and Experimental Electrode Wear Rate

The below given graphical representation 2 show the correlation between the experimental electrode wear rate and the estimated electrode wear rate. The experimental electrode wear rate is the actual electrode wear rate and the estimated electrode wear rates are the values, which are estimated from the regression equation and the main factors current, pulse on time, gap voltage have considered. This is the final regression equation which shows the strongest correlation between machining parameters and the correlation gives R^2 value 97.27 %. The below given figure 2 show the correlation between experimental and estimated roughness value.

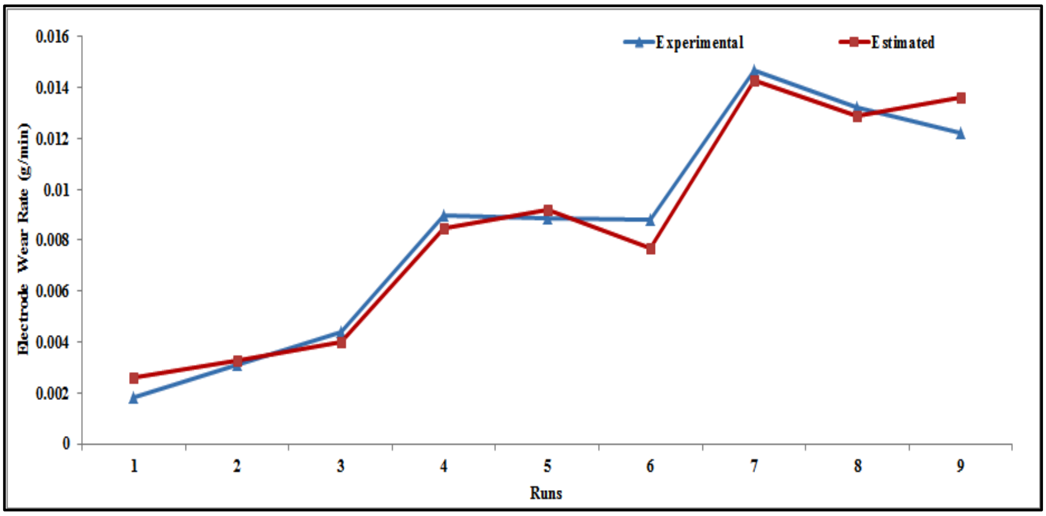

Figure 2: Estimated and Experimental Electrode Wear Rate versus Runs

4.3 Correlation between Estimated Material Removal Rate and Experimental Material Removal Rate

The below given graphical representation 3 show the correlation between the experimental material removal rate and the estimated material removal rate. The experimental material removal rate is the actual material removal rate and the estimated material removal rates are the values, which are estimated from the regression equation and the main factors current, pulse on time, gap voltage have considered. This is the final regression equation which shows the correlation between machining parameters and the correlation gives R^2 value 64.68 %. The below given figure 3 show the correlation between experimental and estimated roughness value.

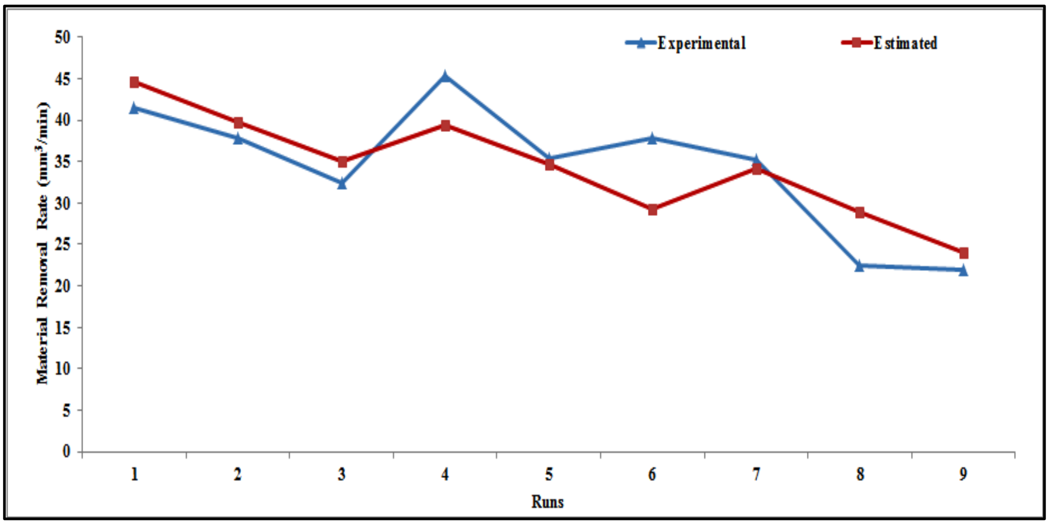

Figure 3: Estimated and Experimental Material Removal Rate versus Runs

V. Conclusions

Based on the experimental results presented in the modeling and discussed in the results and discussion section, the following conclusions are drawn on the effect of discharge current, pulse on time, and gap voltage on the performance of graphite electrode on roughness value, electrode wear rate, and material removal rate of AISI 316 stainless steel.

The conclusions drawn from the analysis are given below:

- In EDM machining, the taguchi method has proved to be efficient tools for controlling the effect machining parameters on roughness value, electrode wear rate, and material removal rate. The current, pulse on time, and gap voltage plays equally important role in the machining process but in analysis these parameters have showed an excellent bonding effect on roughness value prediction and electrode wear rateand less bonding in material removal rate form the regression analysis.
- As the number of machining parameters increases in the correlational analysis the correlation value increases simultaneously. For roughness value the correlation equation would be able to predict the

roughness value with an accuracy of 99.51 %, for electrode wear rate the correlation would be able to predict the electrode wear rate with an accuracy of 97.27%, and for material removal rate the correlation would be able to predict the material removal rate with an accuracy of 64.68 %.

- At last, the machining parameters current, pulse on time, and gap voltage have strong correlation with roughness value and the electrode wear rate, but the less correlation with the material removal rate.

VI. Future Scope

In future, by using the various machining parameters for turning process can also be optimized as follows:

- By using the various statistical analysis software's like SPSS, Minitab, SAS, SYSTAT, FEA, etc. the accuracy of the equation will be improved.
- The various statistical techniques like Regression, Taguchi, Anova, ANN, GA, Fuzzy expert system etc. will improve the performance of equation.
- By using the various parameters the different correlations can be generated.

References

[1]. Banker, K. S., Oza, A. D., & Dave, R. B. Performance Capabilities of EDM machining using Aluminum, Brass and Copper for AISI 304L Material.

[2]. Choudhary, K. K., & Parveen Saini, S. (2013). Analysis of MRR and SR with different electrode for SS 316 on Die-Sinking EDM using Taguchi Technique. Global Journal of Researches In Engineering, 13(3).

[3]. Choudhary, S. K., & Jadoun, R. S. (2014). Current Advanced Research Development of Electric Discharge Machining (EDM): A Review. International Journal of Research in Advent Technology, 2(3).

[4]. Gokulraj, V., Dinesh, A., & Inderajith, M. An Experimental Investigation of Machinability of Stainless Steel 316 Using Brass Electrodes.

[5]. Gopalakannan, S., & Senthilvelan, T. (2012). Effect of Electrode Materials on Electric Discharge Machining of 316 L and 17-4 PH Stainless Steels. Journal of Minerals and Materials Characterization and Engineering, 11(07), 685.

[6]. Klocke, F., Schwade, M., Klink, A., & Veselovac, D. (2013). Analysis of material removal rate and electrode wear in sinking EDM roughing strategies using different graphite grades. Procedia CIRP, 6, 163-167.

[7]. Makwana, A. V., & Banker, K. S. An Electrode Shape Configuration on the Performance of Die Sinking Electric Discharge Machine (EDM): A Review.

[8]. Natarajan, N., & Arunachalam, R. M. (2011). Experimental investigations and optimisation of process parameters in micro-EDM with multiple performance characteristics. International Journal of Experimental Design and Process Optimisation, 2(4), 336-356.

[9]. Sharif, S., Safiei, W., Mansor, A. F., Isa, M. H. M., & Saad, R. M. (2015). Experimental Study of Electrical Discharge Machine (die sinking) on Stainless Steel 316L Using Design of Experiment. Procedia Manufacturing, 2, 147-152.

[10]. Sidhom, H., Ghanem, F., Amadou, T., Gonzalez, G., & Braham, C. (2013). Effect of electro discharge machining (EDM) on the AISI316L SS white layer microstructure and corrosion resistance. The International Journal of Advanced Manufacturing Technology, 65(1-4), 141-153.

[11]. Suresh, P., Venkatesan, R., Sekar, T., Elango, N., & Sathiyamoorthy, V. (2014). Optimization of Intervening Variables in MicroEDM of SS 316L using a Genetic Algorithm and Response-Surface Methodology. Strojniški vestnik-Journal of Mechanical Engineering, 60(10), 656-664.

[12]. Sundaram, C. M., Sivasubramanian, R., & Sivakumar, M. (2013, December). An Experimental Investigation on Machining Parameters of Electrical Discharge Machining of OHNS Steel. In International Journal of Engineering Research and Technology (Vol. 2, No. 12 (December-2013)). ESRSA Publications.

[13]. Tomadi, S. H., Hassan, M. A., Hamedon, Z., Daud, R., & Khalid, A. G. (2009, March). Analysis of the influence of EDM parameters on surface quality, material removal rate and electrode wear of tungsten carbide. In Proceedings of the International MultiConference of Engineers and Computer Scientists (Vol. 2, pp. 18-20).

[14]. Chen, D. C., Jhang, J. J., & Guo, M. W. (2013). Application of Taguchi design method to optimize the electrical discharge machining. Journal of Achievements in Materials and Manufacturing Engineering, 57(2), 76-82.

[15]. Tawfiq, M. A., & Najem, S. H. (2014). Assessment of some factors influencing MRR on the EDM of AISI 304 by Multi Hole Electrode.

[16]. Kumar, N., Kumar, L., Tewatia, H., & Yadav, R. (2012). Comparative study for MRR on die-sinking EDM using electrode of copper and graphite. International Journal of Advanced Technology & Engineering Research, 2(2), 170-174.

[17]. Gopalakannan, S., & Senthilvelan, T. (2012). Effect of Electrode Materials on Electric Discharge Machining of 316 L and 17-4 PH Stainless Steels. Journal of Minerals and Materials Characterization and Engineering, 11(07), 685.

[18]. Purohit, R., Verma, C. S., & Shekhar, P. (2012). Electric discharge machining of 7075al-10 wt.% SiCp composites using rotary tube brass electrodes. Composites, 2(2), 411-423.

[19]. Khan, a. R., Ahmad, M. A., Munir, N., &Butt, Z. R. (2015). Influence of electrode material on quality of blind holes machined via electric discharge machine (die sinker).

[20]. Boujelbene, M., Bayraktar, E., Tebni, W., & Salem, S. B. (2009). Influence of machining parameters on the surface integrity in electrical discharge machining. Archives of Materials Science and Engineering, 37(2), 110-116.

[21]. Gurjar, S. K., & Kumar, R. (2015). Optimization of MRR and TWR on EDM by using Taguchi's Method and ANOVA Die Steel H13. International Journal for Innovative Research in Science and Technology, 2(3), 22-28.

[22]. Nipanikar, S. R. (2012). Parameter optimization of electro discharge machining of AISI D3 steel material by using Taguchi method. J. Eng. Res. Stud, 3, 07-10.

[23]. Santoki, P. N., & Bhabhor, A. P. Parametric Study For Overcut Using EDM With Tool of Graphite, Copper & Silver.

[24]. Syed, K. H., & Palaniyandi, K. (2012). Performance of electrical discharge machining using aluminium powder suspended distilled water. Turkish Journal of Engineering & Environmental Sciences, 36(3), 195-207.

[25]. Roy, T., & Dutta, R. K. Study of the Effect of EDM Parameters based on Tool Overcut using Stainless Steel (SS 304 Grade).

[26]. Bhaumik, M., & Maity, K. P. Study the Effect of Tungsten Carbide Electrode on Stainless Steel (AISI 304) Material in Die Sinking EDM.

[27]. Pawade, M. M., & Banwait, S. S. (2013). A brief review of die sinking electrical discharging machining process towards automation. American Journal of Mechanical Engineering, 1(2), 43-49.
[28]. Mahendran, S., Devarajan, R., Nagarajan, T., & Majdi, A. (2010, March). A review of micro-EDM. In Proceedings of the international multiconference of engineers and computer scientists (Vol. 2).
[29]. Sanghani, C. R., & Acharya, G. D. (2014). A review of research on improvement and optimization of performance measures for electrical discharge machining. Journal of Engineering Research and Applications, 4(1), 433-450.
[30]. GARG, D. R. K., & Ojha, K. (2011, March). A review of tool electrode designs for sinking EDM process. In Proceedings of the 11th WSEAS international conference on robotics, control and manufacturing technology, and 11th WSEAS international conference on Multimedia systems & signal processing (pp. 25-30). World Scientific and Engineering Academy and Society (WSEAS).