"Comparative Study & Optimization of EDM Process Parameters Using Different Shape of Tool"

Harish R Patel[1], V. D. Patel[2]

[1]P.G. Student Production (mechanical), LDRP-ITR, Gujarat, India
[2]Assistant Professor, Mechanical Engineering, LDRP-ITR, Gujarat, India

ABSTRACT

The correct selection of manufacturing conditions is one of the most important aspects to take into consideration in the majority of manufacturing processes and, particularly, in processes related to Electrical Discharge Machining (EDM). It is a 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, carbides, heat resistant steels etc. being widely used in die and mold making industries, aerospace, aeronautics and nuclear industries. 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 workpiece material selected in this experiment is Stavex taking into account its wide usage in industrial applications. In today's world Stavex contributes to almost half of the world's production and consumption for industrial purposes. The tool material is copper & brass. The input variable parameters are current, pulse on time and pulse of time. Taguchi method is applied to create an L9 orthogonal array of input variables 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) and Overcut (OC) study and investigate.

Keyword : - MRR, TWR, OC, DOE, EDM, OA

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1. INTRODUCTION

Electric Discharge Machining (EDM) is a nontraditional machining process in the sense that they do not employ traditional tools for metal removal and instead directly by means of electric spark erosion [5]. It is developed in the late 1940s, has been accepted worldwide as a standard process in manufacture of forming tools to produce plastics molding, die castings, forging dies etc. 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 [1].

The recent developments in the field of EDM have progressed due to the growing application of EDM process and the challenges being faced by the modern manufacturing industries, from the development of new materials that are hard and difficult-to-machine such as tool steels, composites, ceramics, super alloys, hastalloy, nitralloy, carbides, stainless steels, heat resistant steel, etc. being widely used in die and mould making industries, aerospace, aeronautics, and nuclear industries. Many of these materials also find applications in other industries owing to their high strength to weight ratio, hardness and heat resisting qualities. EDM has also made its presence felt in the new fields such as sports, medical and surgical instruments, optical, dental and jewellery industries, including automotive R&D areas [1].

The adequate selection of manufacturing conditions is one of the most important aspects to take into consideration in the die-sinking electrical discharge machining (EDM) of conductive steel, as these conditions are the ones that are to determine such important characteristics: Overcut(OC), Surface Roughness (SR), Tool Wear Rate (TWR) and Material Removal Rate (MRR) [2]. In this paper, a study of Overcut performed on the influence of the factors of Current, Pulse on Time & Pulse off Time.

2. PRINCIPLE OF EDM

In this process the metal is removing from the work piece due to erosion case by rapidly recurring spark discharge taking place between the tool and work piece. A thin gap about 0.025mm is maintained between the tool and work piece by a servo system shown in fig 1. Both tool and work piece are submerged in a dielectric fluid Kerosene/EDM oil/de-ionized water is very common type of liquid dielectric although gaseous dielectrics are also used in certain cases. Basically, there are two different types of EDM: Die-sinking EDM & Wire-cut EDM. A EDM system has four major Components: (1) Computerized Numerical Control (CNC), (2) Power Supply, (3) Mechanical Section : Worktable, work stand, taper unit etc., (4) Dielectric System[8].

3. LITERATURE REVIEW

Shankar Singh et. al. [1] evaluate that Electric Discharge Machining (EDM), a 'non-traditional machining process', has been replacing drilling, milling, grinding and other traditional machining operations and is now a well-established machining option in many manufacturing industries throughout the world. This paper reports the results of an experimental investigation carried out to study the effects of machining parameters such as pulsed current on material removal rate, diameteral overcut, electrode wear, and surface roughness in electric discharge machining of En-31 tool steel (IS designation: T105 Cr 1 Mn 60) hardened and tempered to 55 HRc. The work material was ED machined with copper, copper tungsten, brass and aluminium electrodes by varying the pulsed current at reverse polarity. Investigations indicate that the output parameters of EDM increase with the increase in pulsed current and the best machining rates are achieved with copper and aluminium electrodes. After analysing the results of the experiments on En-31 tool steel with different electrode materials, the following conclusion are arrived at: For the En-31 work material, copper and aluminium electrodes offer higher MRR. Diameteral overcut produced on En-31 is comparatively low when using copper and aluminium electrodes, which may be preferred for En-31 when low diameteral overcut (higher dimensional accuracy) is the requirement. Copper and copper–tungsten electrodes offer comparatively low electrode wear for the tested work material. Aluminium electrode also shows good results while brass wears the most, of all the tested electrodes.Of the four tested electrode materials, Cu and Al electrodes produce comparatively high surface roughness for the tested work material at high values of currents. Copper–tungsten electrode offers comparatively low values of surface roughness at high discharge currents giving good surface finish for tested work material. Copper is comparatively a better electrode materials as it gives better surface finish, low diameteral overcut, high MRR and less electrode wear for En-31 work material, and aluminium is next to copper in performance, and may be preferred where surface finish is not the requirement.

Othman Belgassim et. al. [7] used L9 orthogonal array based on Taguchi method to conduct a series of experiments to optimize the EDM parameters. Experimental data were evaluated statistically by analysis of variance (ANOVA). The EDM parameters are Pulse current (I_p), Pulse –on- time (T_{on}), Pulse –off- time (T_{off}), and the Gap voltage (V_g) , while the machining responses in concern are the surface roughness of the machined surface and the over-cut. The experimental results have given optimal combination of input parameters which give the optimum surface finish of the EDM surface.

S.H.Tomadi et. al. [2] evaluate that the influence of operating parameters of tungsten carbide on the machining characteristics such as surface quality, material removal rate and electrode wear. The effectiveness of EDM process with tungsten carbide, WC-Co is evaluated in terms of the material removal rate, the relative wear ratio and the surface finish quality of the workpiece produced. It is observed that copper tungsten is most suitable for use as the tool electrode in EDM of WC-Co. Better machining performance is obtained generally with the electrode as the cathode and the workpiece as an anode. In this paper, a study was carried out on the influence of the parameters such peak current, power supply voltage, pulse on time and pulse off time. The surface quality that was investigated in this experiment was surface roughness using perthometer machine. Material removal rate (MRR) and electrode wear (EW) in this experiment was calculated by using mathematical method. The result of the experiment then was collected and analyzed using STATISTICA software. This was done by using the design of experiments (DOE) technique and ANOVA analysis.

Subramanian Gopalakannan et. al. [3] study the effect of pulsed current on material removal rate, electrode wear, surface roughness and diameter overcut in corrosion resistant stainless steels viz., 316 L and 17-4 PH. The materials used for the work were machined with different electrode materials such as copper, cop-per-tungsten and graphite. It is observed that the output parameters such as material removal rate, electrode wear and surface roughness of EDM increase with increase in pulsed current. The results reveal that high material removal rate have been achieved with copper electrode whereas copper-tungsten yielded lower electrode wear, smooth surface finish and good dimensional accuracy.

V.Balasubramaniam et. al. [4] used different electrode materials namely copper, brass and tungsten while EDM of Al-SiCp Metal Matrix Composite. Material Removal Rate (MRR), Electrode Wear Rate (EWR) and Circularity (CIR) are considered as the performance measures. Artificial Neural Network is used for optimization of the machining parameters such as current, pulse on time and flushing pressure. Investigations indicate that the current is the most significant parameter. Among the three electrodes copper yields better performances. Machining time is reduced with better performances.

Praveen Kumar Singh et. al. [5] focused on the effect of Copper and Brass electrodes on material removal rate (MRR) and tool wear rate (TWR) for AISI D2 tool steel by using Die- Sinker EDM. The current was varied from 4 to 10 amp, the voltage and flushing pressure were constant, the MRR for copper electrode was in the range of 4.8139 -22.6580 mm3/min whereas the range of MRR for brass electrode was 7.2213-9.8203 gm/min. The trend of TWR as shown in results increases with current for both the electrodes. The effect of voltage on MRR and TWR for both the electrodes was analyzed. The MRR for copper electrode was continuously decreasing with voltage whereas MRR for brass don't follow any specific trend. The TWR for both the electrodes decreases with voltage. It has been observed that copper electrode is the best for machining AISI D2 tool steel by using Die- Sinker EDM.

4 EXPERIMENTAL SETUP & DOE

The electric discharge machine, model SPARKONIX SN-25 (die-sinking type) with servo-head (constant gap) and positive polarity for electrode was used to conduct the experiments. Spark Erosion EDM oil was used as dielectric fluid.

Material to be used as workpiece- AISI 316SS

Electrode to be used- Copper, having 10.00 mm diameter.

Variable Input Parameters- Current, Pulse on time, Pulse off time.

Constant Input Parameter- Voltage[50 V], Flushing Pressure[0.5 lb/m^2]

Depth of Cut- 3 mm

Experiment has to be done at Jayvir Engineering, Ahmadabad.

DOE Adopted : Taguchi L9 Orthogonal Array

Overcut is calculated by, Overcut = [Diameter of Hole - Diameter of Tool] / 2

MRR is calculated by, MRR = [Weight of Workpiece Before Machining – Weight of Workpiece After Machining] / [Time * Density of Workpiece Material]

TWR is calculated by, TWR = [Weight of Tool Before Machining – Weight of Workpiece After Machining]/ Time

Table 1. Chemical composition of AISI 316SS

Material	C	Cr	Fe	Mn	Ni	P	S	Si	N
AIS316 Wt. %	Max 0.08	18-20	66.345-74	Max 2	8-10.5	Max 0.045	Max 0.03	0.75	0.1

Typical Application of AISI 316 SS in : Chemical Equipments, Cooking Equipments, Cooling coil, Evaporators, Food Processing Equipments, Hospital Equipments, Refrigerator Equipments, Paper & Rubber Industry. Corrosion Resistant & Stain Resistant , use in P.V.C, acetates and for mould subjected to humid working. Wear Resistant i.e. for moulding abrasive/filled material , including Injection-moulded thermosetting grades. High surface finish for production of optical parts ,such as camera and sunglasses lenses and for medical container.

Technical Reasons for Selecting Copper: Copper can produce very fine surface finishes. Also Copper has high electrical conductivity [1.04 * 10^7 Siemens/meter], Sufficiently high melting point [1083 ◦C]. Easily available & low in cost [10].

The L9 Orthogonal Array methodology has been used to plan the experiments. Three factors are chosen the design becomes a 3 level 3 factorial Taguchi design. The version 16 of the MINITAB software was used to develop the experimental plan for L9 Orthogonal Array.

Table 2. Factors with Levels

Factors	**Notation**	**Levels**		
		1	**2**	**3**
Current (Amps)	Ip	4	8	15
Pulse on Time (µs)	Ton	5	6	7
Pulse off Time (µs)	Toff	4	5	6

5. EXPERIMENTAL RESULT & ANALYSIS

The effect of process parameters on the machining parameter is recorded in the table. The nine experiments done on the electro discharge machine based on the Taguchi method and summarized in the following table.

Table 3. Experimental Results For Round Shape Copper Tool

Run No.	Current (Amps)	Pulse on Time (µs)	Pulse off Time (µs)	Overcut (mm)	Material Removal Rate (mm3/min)	Tool Wear Rate (gm/min)
				OC	MRR	TWR
1	4	5	4	0.025	4.687	0.0002202
2	4	6	5	0.030	6.225	0.0001883
3	4	7	6	0.035	8.001	0.0001060
4	8	5	5	0.030	8.205	0.0021420
5	8	6	6	0.045	30.231	0.0020000
6	8	7	4	0.055	33.369	0.0026714
7	15	5	6	0.042	30.572	0.0079787
8	15	6	4	0.055	37.598	0.0098684
9	15	7	5	0.065	40.758	0.0114068

Table 4. Experimental Results For Square Shape Copper Tool

Run No.	Current (Amps)	Pulse on Time (µs)	Pulse off Time (µs)	Overcut (mm)	Material Removal Rate (mm3/min)	Tool Wear Rate (gm/min)
				OC	MRR	TWR
1	4	5	4	0.028	4.975	0.0004
2	4	6	5	0.033	6.447	0.0005
3	4	7	6	0.038	7.890	0.0006
4	8	5	5	0.031	8.405	0.0013
5	8	6	6	0.048	31.401	0.0025
6	8	7	4	0.058	34.375	0.003
7	15	5	6	0.044	31.562	0.0062
8	15	6	4	0.058	39.583	0.0072
9	15	7	5	0.068	41.875	0.0083

5.1 Normality Testing For Round Shape Copper Tool

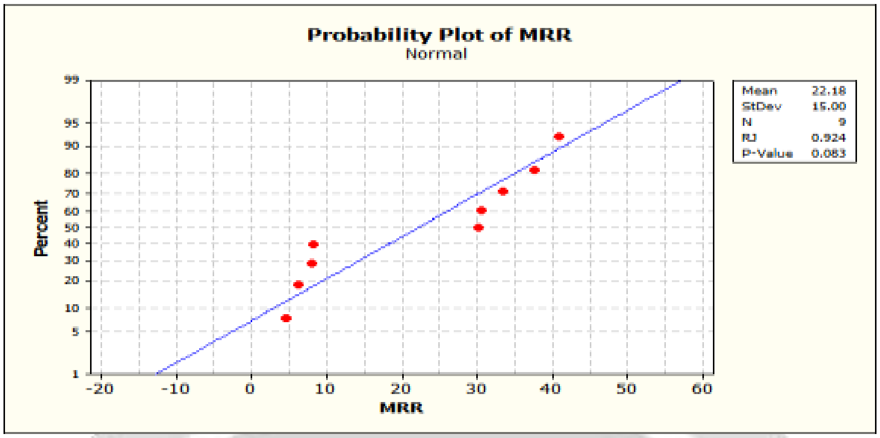

figure 1. Normality Testing For MRR

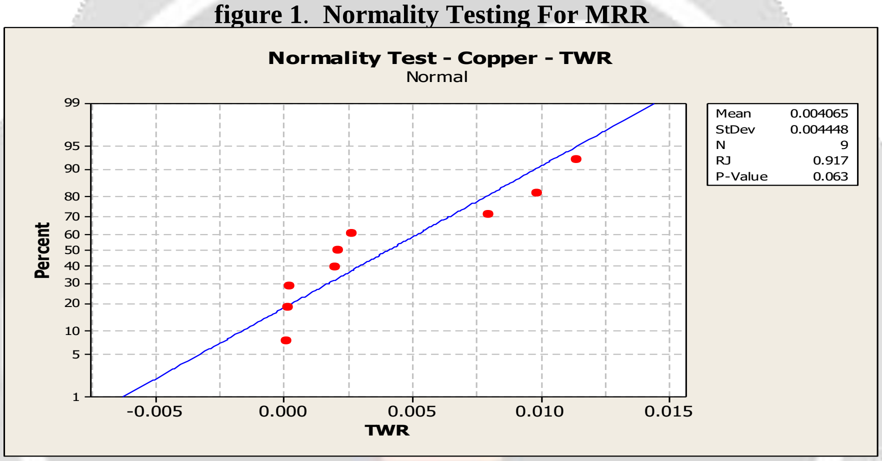

figure 2. Normality Testing For TWR

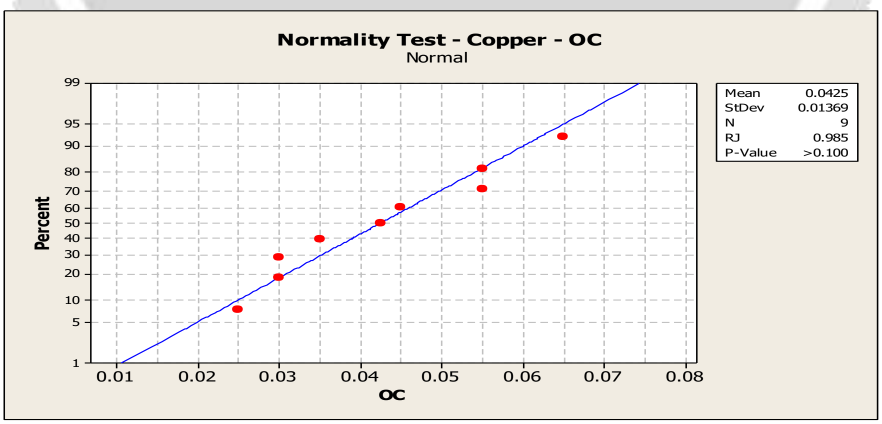

figure 3. Normality Testing For OC

Here, from above all graphs we can see that the P value of normality test is $P \geq 0.05$. So, the data follows all the natural phenomena & it is normal.

5.2 Normality Testing For Square Shape Copper Tool

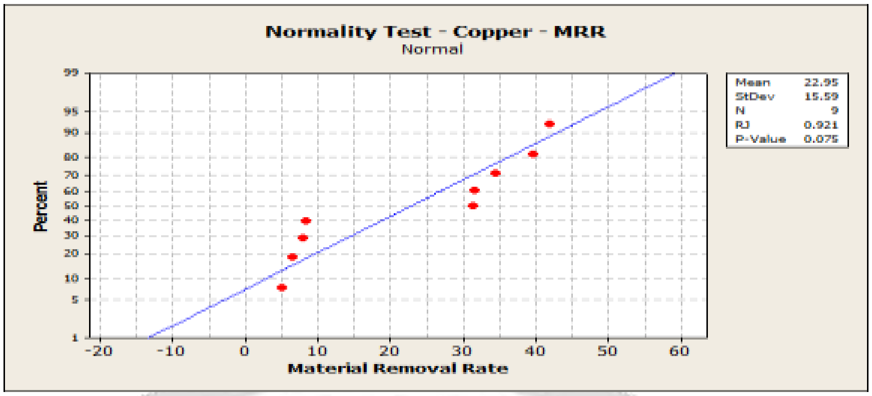

fig 4. Normality Testing For MRR

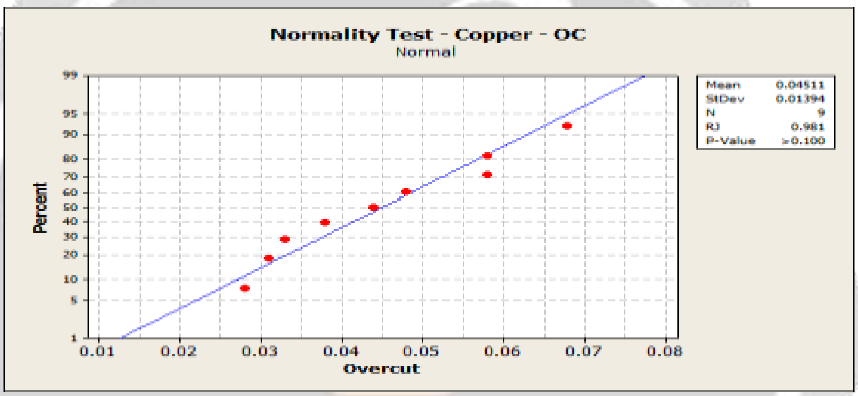

figure 5. Normality Testing For OC

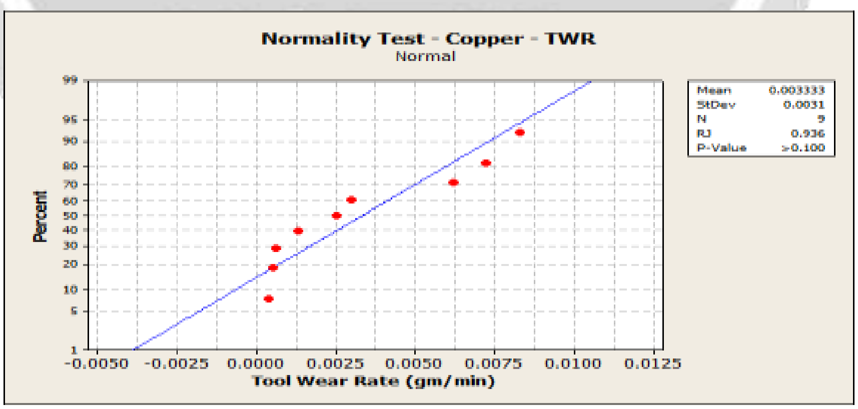

figure 6 . Normality Testing For TWR

Here, from above all graphs we can see that the P value of normality test is P ≥ 0.05. So, the data follows all the natural phenomena & it is normal.

5.3 Main Effect Plot For Round Shape Copper Tool

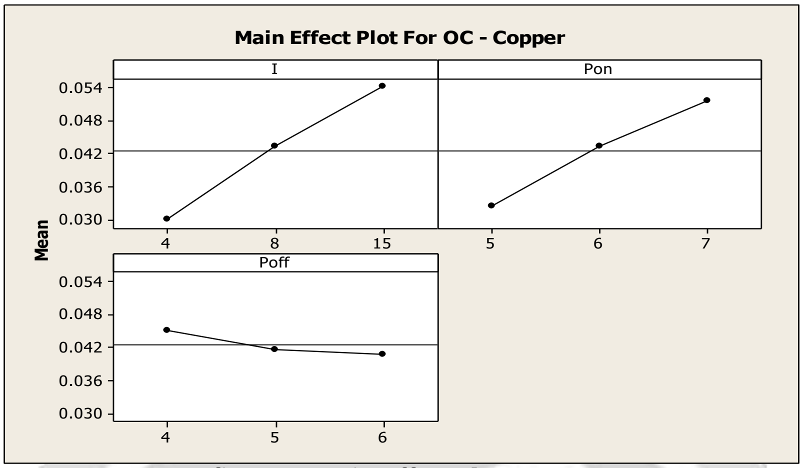

figure 7. Main Effect Plot For OC

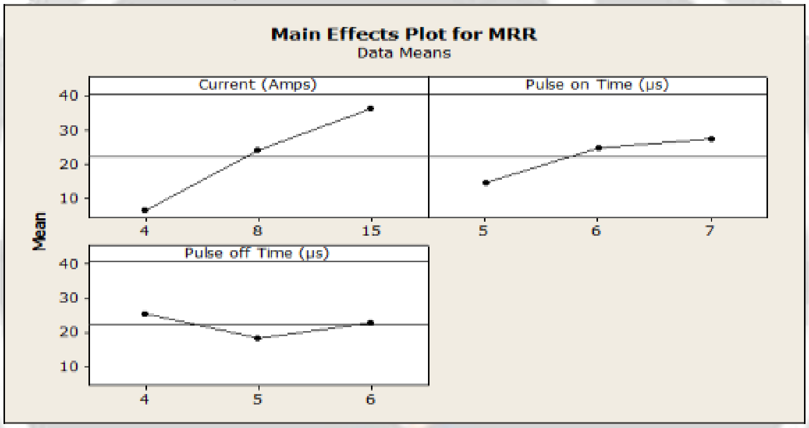

figure 8. Main Effect Plot For MRR

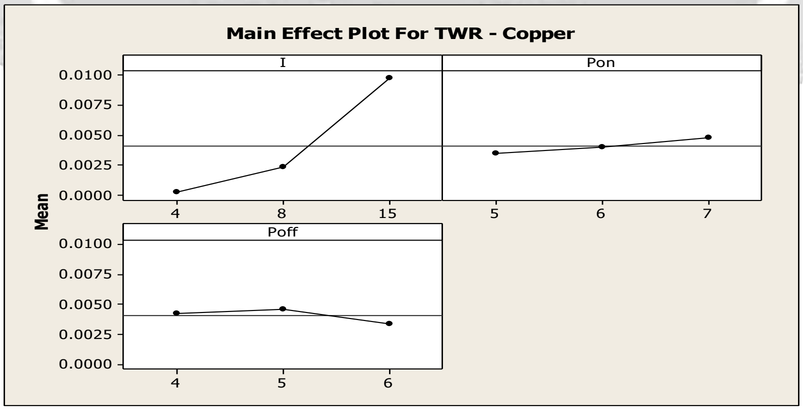

figure 9. Main Effect Plot For TWR

5.4 Main Effect Plot For Square Shape Copper Tool

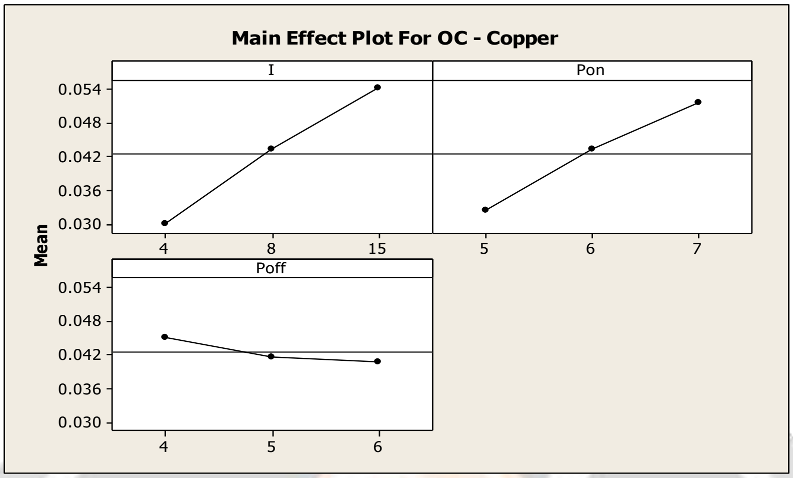

figure 10. Main Effect Plot For OC

figure 11. Main Effect Plot For MRR

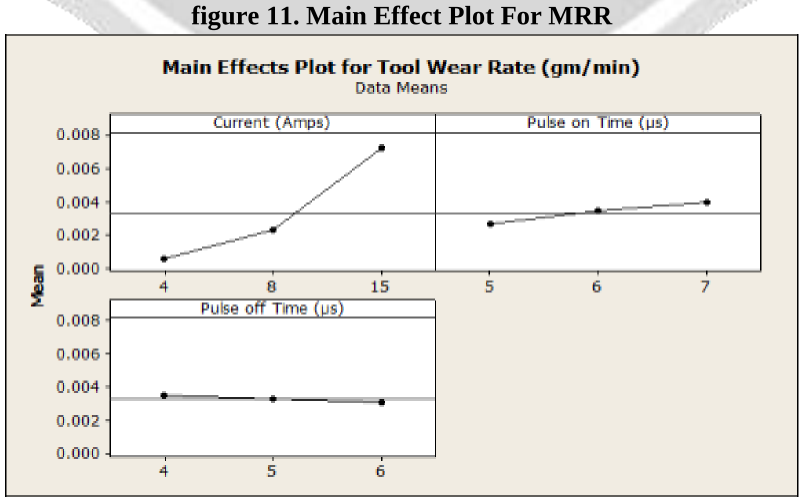

figure 12. Main Effect Plot For TWR

5.5 Interaction Plot For Round Shape Copper Tool

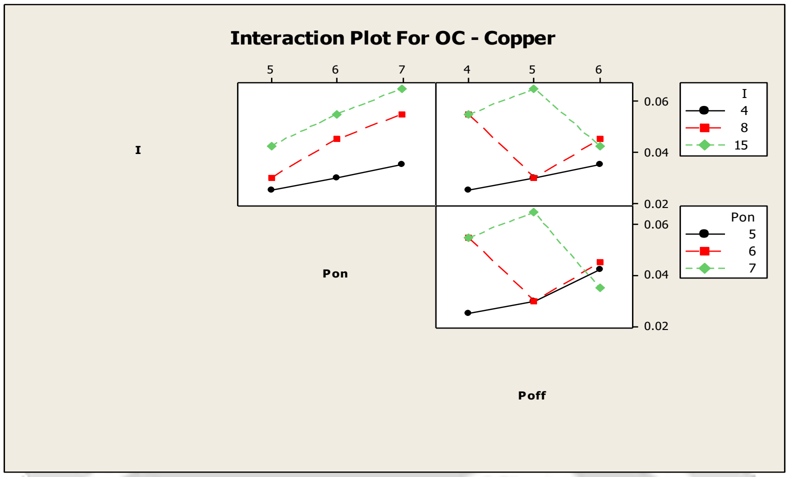

figure 13. Interaction Plot For OC

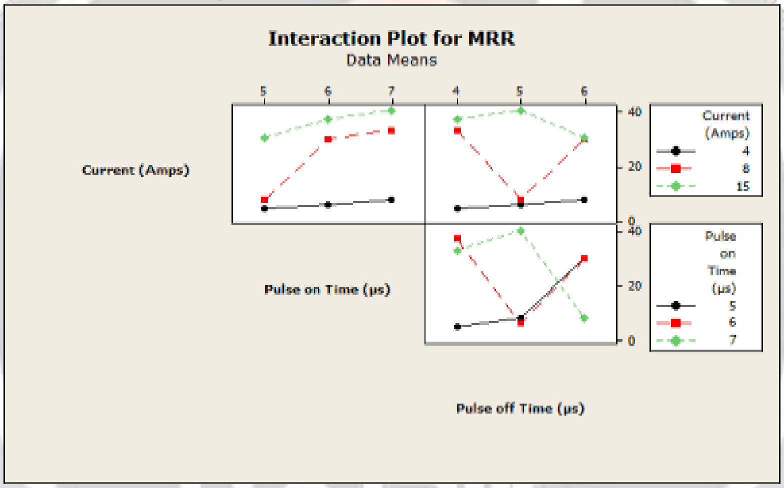

figure 14. Interaction Plot For MRR

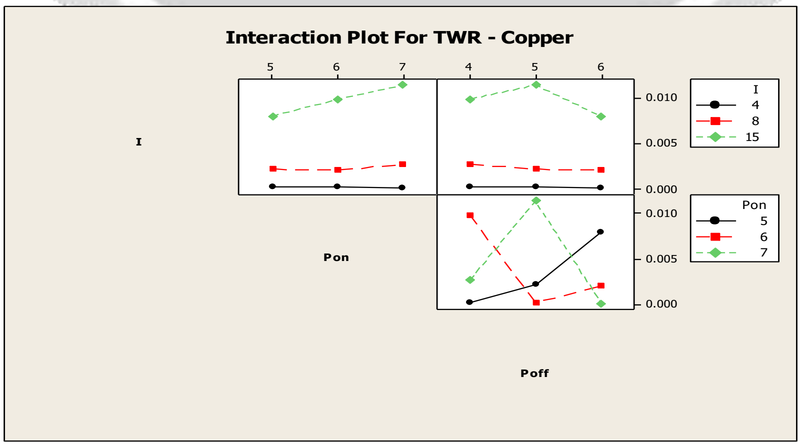

figure 15. Interaction Plot For TWR

5.6 Interaction Plot For Square Shape Copper Tool

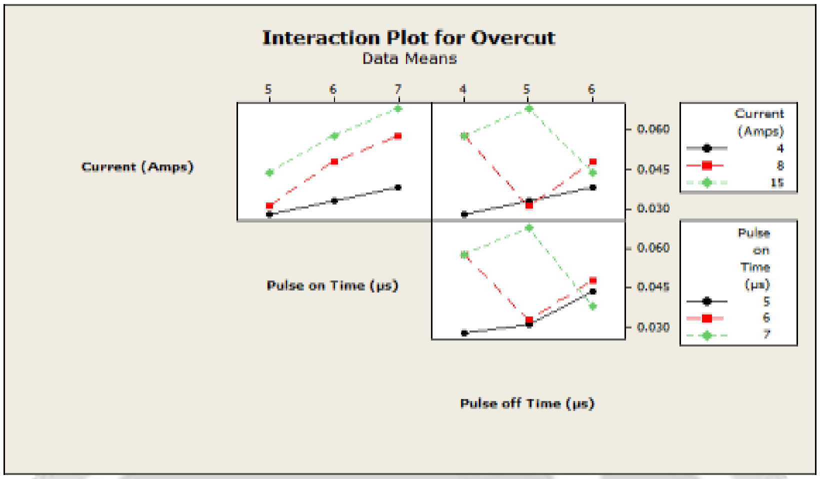

figure 16. Interaction Plot For OC

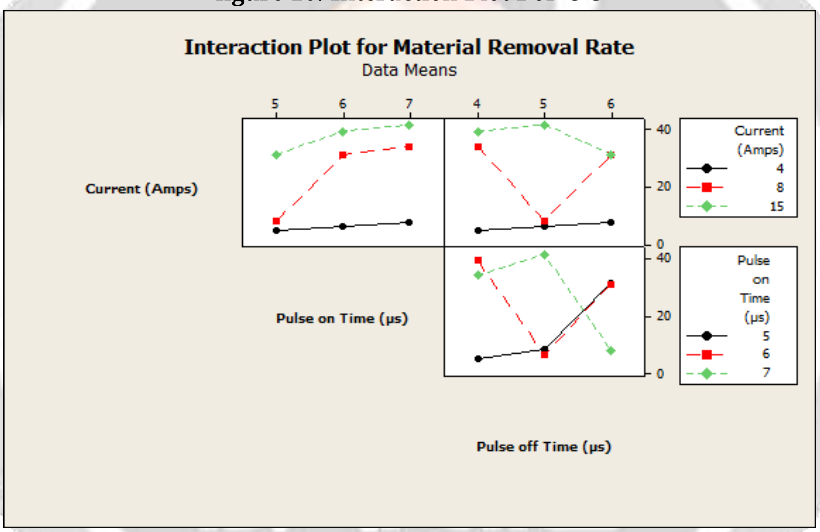

figure 17. Interaction Plot For MRR

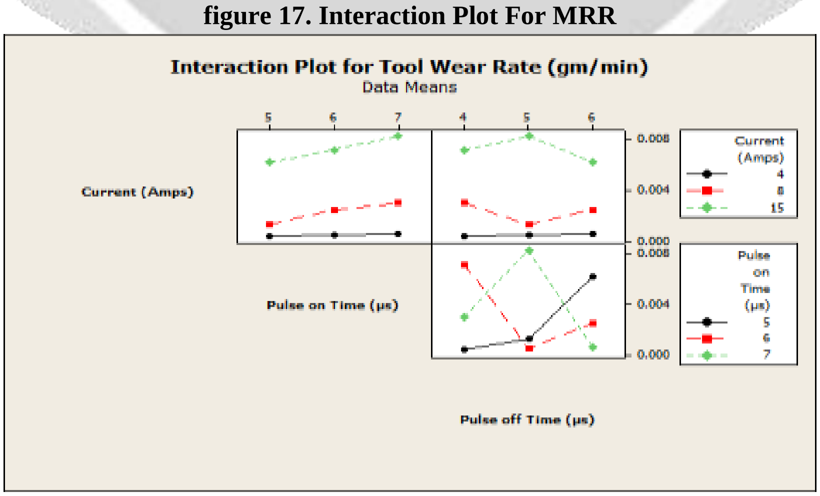

figure 18. Interaction Plot For TWR

5.7 Regression Model Analysis

5.7.1 Regression Model For Round Shape Copper Tool

- **Regression Model analysis for OC of Copper :**

The Regression equation is OC = - 0.0237 + 0.00211 Current + 0.00967 Pon - 0.00217 Poff

Table 5. Regression Model analysis for OC

Source	P
Regression	0.002
R-Sq = 94.3%	R-Sq(adj) = 90.9%

- **Regression Model analysis for MRR of Copper :**

The Regression equation is MRR = - 34.3 + 2.62 Current + 6.44 Pon - 1.14 Poff

Table 6. Regression Model analysis for MRR

Source	P
Regression	0.016
R-Sq = 85.2%	R-Sq(adj) = 82.2%

- **Regression Model analysis for TWR of Copper :**

The Regression equation is TWR = - 0.00559 + 0.000893 Current + 0.000641 Pon - 0.000446 Poff

Table 7. Regression Model analysis for TWR

Source	P
Regression	0.001
R-Sq = 96.1%	R-Sq(adj) = 93.7%

5.7.2 Regression Model For Square Shape Copper Tool

- **Regression Model analysis for OC of Copper :**

The Regression equation is OC = - 0.0230 + 0.00209 Current + 0.0102 Pon - 0.00233 Poff

Table 8. Regression Model analysis for OC

Source	P
Regression	0.002
R-Sq = 94.0%	R-Sq(adj) = 90.5%

- **Regression Model analysis for MRR of Copper :**

The Regression equation isMRR = - 34.1 + 2.73 Current + 6.53 Pon - 1.35 Poff

Table 9. Regression Model analysis for MRR

Source	P
Regression	0.017
R-Sq = 84.9%	R-Sq(adj) = 82.8%

- **Regression Model analysis for TWR of Copper :**

The Regression equation is TWR = - 0.00519 + 0.000623 Current + 0.000667 Pon - 0.000217 Poff

Table 10. Regression Model analysis for TWR

Source	P
Regression	0.000
R-Sq = 97.8%	R-Sq(adj) = 96.4%

Here, from above regression model we can see that the P value of model is $P \leq 0.05$. So, the model follows all the natural phenomena & it is fit.

5.8 Optimization Problem Formulation

The aim of present study was to determine the set of optimal parameters of EDM process to ensure minimum overcut & tool wear rate and maximum material removal rate.

5.8.1 GA Function for Copper Tool _ Round

```
function OC = DOE_OCG(x)
OC = - 0.0237 + 0.00211 * x(1) + 0.00967 * x(2) - 0.00217 * x(3);
function MRR = DOE_MRRG(x)
MRR = - ( -34.3 + 2.62 * x(1) + 6.44 * x(2) – 1.14 * x(3));
function TWR = DOE_TWRG(x)
TWR = - 0.00559 + 0.000893 * x(1) + 0.000641 * x(2) - 0.000446 * x(3);
```

5.8.2 GA Function for Copper Tool _ Square

```
function OC = DOE_OCC(x)
OC = - 0.0230 + 0.00209 * x(1) + 0.0102 * x(2) - 0.00233 * x(3);
function MRR = DOE_MRRC(x)
MRR = - (- 34.1 + 2.73 * x(1) + 6.53 * x(2) – 1.35 * x(3));
function TWR = DOE_TWRC(x)
TWR = - 0.00519 + 0.000623 * x(1) + 0.000667 * x(2) - 0.000217 * x(3);
```

✓ Constraints for all the three functions are as follows:

- Current x(1) : $I_{min} \leq x(1) \leq I_{max}$, i.e. 4 A ≤ I ≤ 15 A
- Pulse on Time x(2) : $Pon_{min} \leq x(2) \leq Pon_{max}$, i.e. 5 µs ≤ Pon ≤ 7 µs
- Pulse off Time x(3) : $Poff_{min} \leq x(3) \leq Poff_{max}$, i.e. 4 µs ≤ Poff ≤ 6 µs

5.9 Optimization using MATLAB Tool box

5.9.1 Results of optimization using GA [Copper Tool_Round]

➢ **Optimized value of Overcut for Copper Tool using GA :**

Table 11. Optimized Value of Overcut

Ext No.	Process Variables			Response
	I	Pon	Poff	OC
Population size : 50				
1	4	5	6	0.020

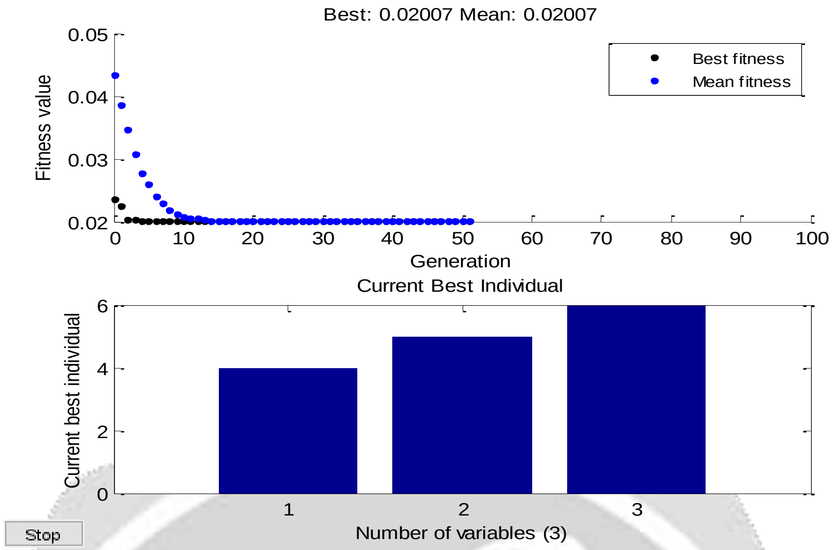

Fig. 1 Plots of best fitness and best individual for GA using regression equations

- **Optimized value of MRR for Copper Tool using GA :**

Table 12. Optimized Value of MRR

Ext No.	Process Variables			Response
	I	Pon	Poff	MRR
Population size : 50				
1	15	7	5	45.51

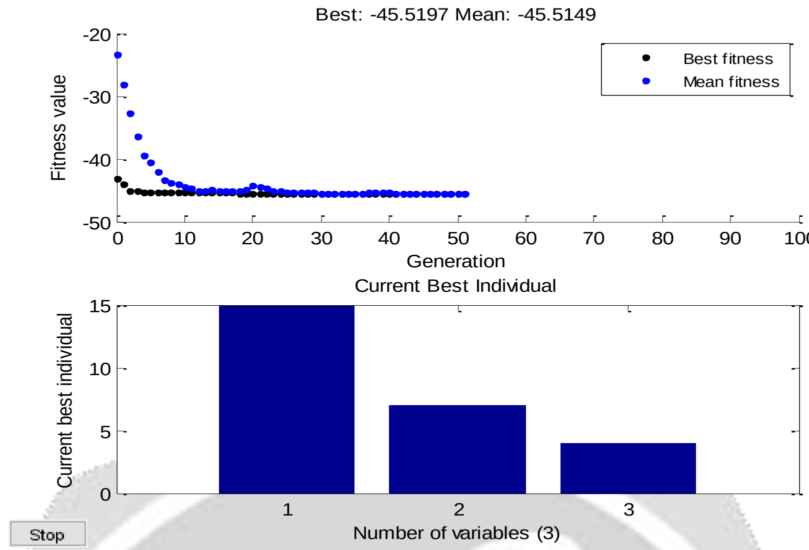

Fig. 2 Plots of best fitness and best individual for GA using regression equations

- **Optimized value of TWR for Copper Tool using GA :**

Table 13. Optimized Value of TWR

Ext No.	Process Variables			Response
	I	Pon	Poff	TWR
Population size : 50				
1	4	5	6	0.000028

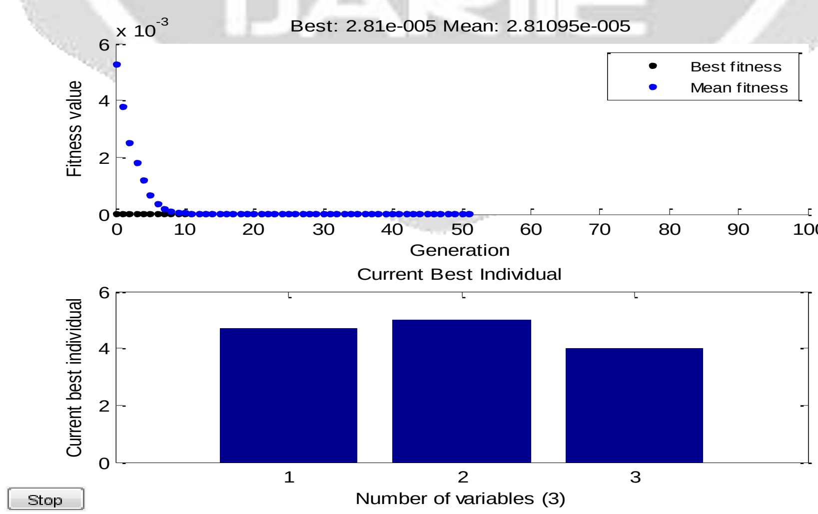

Fig. 3 Plots of best fitness and best individual for GA using regression equations

5.9.2 Results of optimization using GA [Copper Tool_Square]

- **Optimized value of Overcut for Copper Tool using GA :**

Table 14. Optimized Value of Overcut

Ext No.	Process Variables			Response
	I	Pon	Poff	OC
Population size : 50				
1	4	5	6	0.022

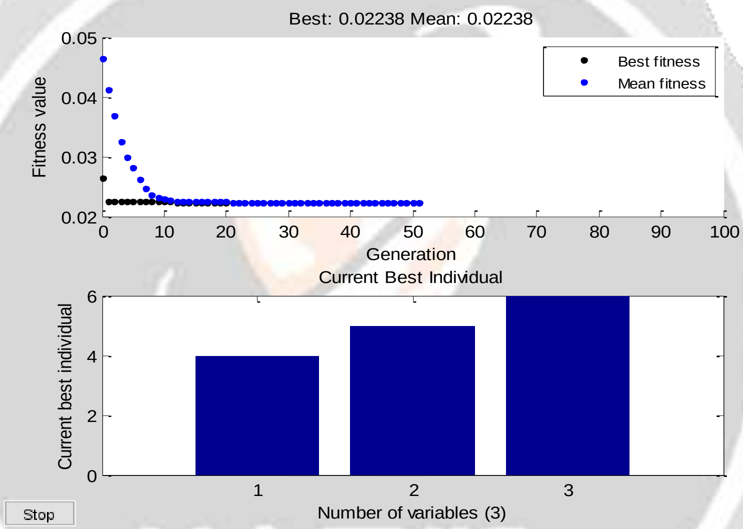

Fig. 4 Plots of best fitness and best individual for GA using regression equations

- **Optimized value of MRR for Copper Tool using GA :**

Table 15. Optimized Value of MRR

Ext No.	Process Variables			Response
	I	Pon	Poff	MRR
Population size : 50				
1	15	7	5	45.51

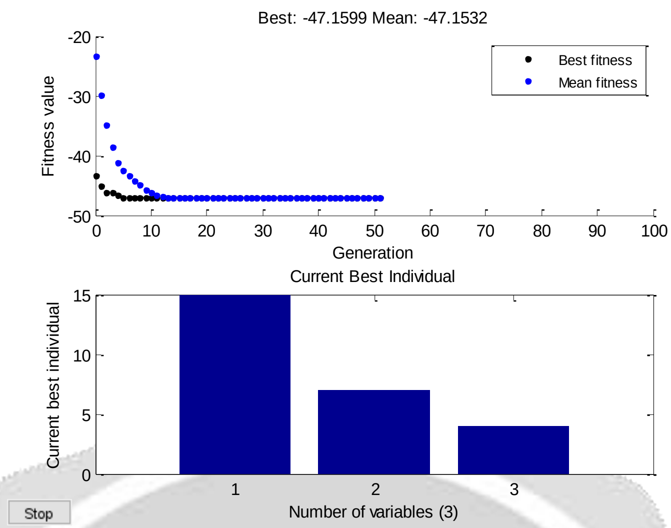

Fig. 5 Plots of best fitness and best individual for GA using regression equations

➢ Optimized value of TWR for Copper Tool using GA :

Table 16. Optimized Value of TWR

Ext No.	Process Variables			Response
	I	Pon	Poff	TWR
Population size : 50				
1	4	5	6	0.000018

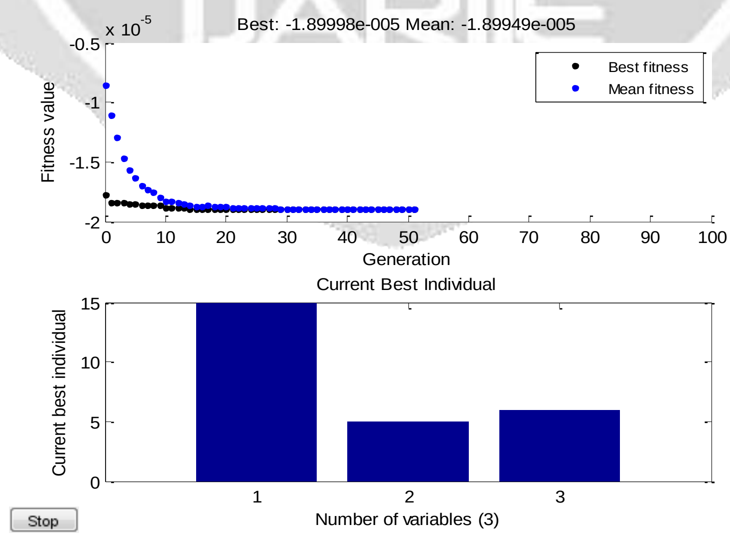

Fig. 6 Plots of best fitness and best individual for GA using regression equations

5.10 Validation through Practical Experiment

The results obtained through optimization had to be validated. This was done through practical performance of the experiment in the same manner as the practicals performed earlier as per DOE. The results are tabulated as under :

Table 17. Validatory Experiment # 1 (As per Regression Model) (Copper Tool-Round)

Input Parameters	Value*	Optimized value of Overcut	Experimental value of Overcut	% Error
Current	4 A	0.020	0.021	4.76%
Pulse on Time	5 µs			
Pulse off Time	6 µs			

Input Parameters	Value*	Optimized value of MRR	Experimental value of MRR	% Error
Current	15 A	45.51	46.01	1.08%
Pulse on Time	7 µs			
Pulse off Time	5 µs			

Input Parameters	Value*	Optimized value of TWR	Experimental value of TWR	% Error
Current	4 A	0.000028	0.000029	3.44%
Pulse on Time	5 µs			
Pulse off Time	6 µs			

Table 18. Validatory Experiment # 2 (As per Regression Model) (Copper Tool-Square)

Input Parameters	Value*	Optimized value of Overcut	Experimental value of Overcut	% Error
Current	4 A	0.022	0.023	4.34%
Pulse on Time	5 µs			
Pulse off Time	6 µs			

Input Parameters	Value*	Optimized value of MRR	Experimental value of MRR	% Error
Current	15 A	47.15	48.04	1.85%
Pulse on Time	7 µs			
Pulse off Time	4 µs			

Input Parameters	Value*	Optimized value of TWR	Experimental value of TWR	% Error
Current	4 A	0.000018	0.000019	5.26%
Pulse on Time	5 µs			
Pulse off Time	6 µs			

6. CONCLUSION

After analysing the results of the experiments on AISI316SS with different shape of electrode materials, the following conclusion are arrived :

- **We Find The Below Conclusion..For Square Tool,**

- OC is increased with increasing by Current & Pon Time. OC is decrease with increasing by Poff Time.
- MRR is increased with increasing by Current & Pon Time.
- MRR is first decreased then increase with increasing Poff Time.
- TWR is increased with increasing Current & Pon Time.
- TWR is first increased then decrease with increasing Poff Time.

- **We Find The Below Conclusion..For Square Tool,**

- OC is increased with increasing by Current & Pon Time.
- OC is decreased with increasing by Poff Time.
- MRR is increased with increasing by Current & Pon Time.
- MRR is first decreased then increase by increasing Poff Time.
- TWR is increased by increasing Current & Pon Time.
- TWR is first increased by increasing Poff Time.

Finally it is found that the copper tool is more suitable. The experimental results indicate that the Poff significantly affects the OC followed by current & pulse on time. Current significantly affects the MRR followed by pulse on time & pulse off time. Pulse on time significantly affect the TWR followed by current & pulse off time.

7. FUTURE SCOPE

- In the present the regression was used. The empirical models will also use for comparison with regression models.
- Different tool materials such as Brass, Tungsten, Copper Tungsten, Silver Tungsten, Tungsten Carbide, Aluminum can be used.
- Other process parameters such as Polarity, Gap Voltage, Duty cycle, Flushing Pressure can be used for analysis & also find out the surface roughness of work piece material.
- Multi – objective optimization can be done for the performance parameters.
- Work piece materials such as EN31 Tool Steel, Tungstan-Carbied, V Composite, Al 7075 B4C MMC, AISI 202 SS, AISI D3 Tool Steel, H-11 Steel, H-13 Tool Steel, Hastelloy Steel, Mild Steel, AISI 1040 Medium Carbon Steel, EN19, EN9, AISI 316-L SS, NiTi60-SMA, AISI D2 Tool Steel, Ai-SiCP MMC, AISI P20 Tool Steel, Silver Steel, W300 Die Steel, AISI 4340 Steel, Titanium Super Alloy. etc can be used.

REFERENCES

[1] Shankar Singh et. al.,"Some investigations into the electric discharge machining of hardened tool steel using different electrode materials",*Journal of Materials Processing Technology 149 (2004) 272–277.*

[2] S.H.Tomadi et. al.," Analysis of the Influence of EDM Parameters on Surface Quality, Material Removal Rate and Electrode Wear of Tungsten Carbide", *Proceedings of the International MultiConference of Engineers and Computer Scientists 2009 Vol II IMECS 2009, March 18 - 20, 2009, Hong Kong.*

[3] Subramanian Gopalakannan et. al.,"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, 2012, 11, 685-690 Published Online July 2012.*

[4] V.Balasubramaniam et. al.," Optimization of Electrical Discharge Machining Parameters Using Artificial Neural Network With Different Electrodes", *5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th–14th, 2014, IIT Guwahati, Assam, India.*

[5] Praveen Kumar Singh et. al.," Parametric studies for MRR and TWR using die sinking EDM with electrode of Copper and Brass", *Proc. of the Intl. Conf. on Advances In Engineering And Technology - ICAET-2014, ISBN: 978-1-63248-028-6 doi: 10.15224/ 978-1-63248-028-6-03-145.*

[6] Priyesh N. Santoki et. al., "A Review - Status of Recent Developments & Effect of Machining Parameters on Performance Parameters in EDM.", *International Journal of Innovative and Emerging Research in Engineering Vol. X, No. X, 2015*.

[7] Othman Belgassim et. al., "Optimization of the EDM Parameters on the Surface Roughness of AISI D3 Tool Steel", *Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management Istanbul, Turkey, July 3 – 6, 2012.*

[8] Priyesh N. Santoki et. al., "A Review - Status of Recent Developments & Effect of Machining Parameters on Performance Parameters in EDM.", *International Journal of Innovative and Emerging Research in Engineering Vol. X, No. X, 2015*.

[9] Instruction and Maintenance Manual For Spark Erosion Machine by Sparkonix Pvt. Ltd.

[10] Techtips by Roger Kern.