Comparative Optimization of Different Tool Material on AISI 2136 (Plastic Mould Steel) Using EDM

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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) will 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 [A.40]. 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 [A.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 [A.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) [A.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[A.41].

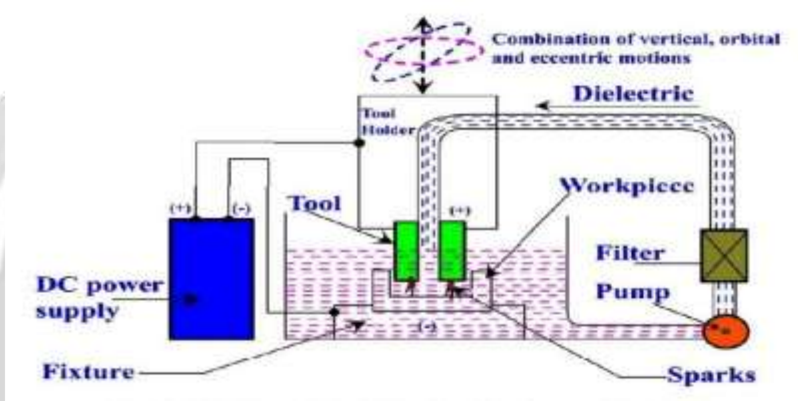


Fig 1. Setup of EDM [B.1]

3. LITERATURE REVIEW

Shankar Singh et. al. [A.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. [A.42] 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. [A.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. [A.25] 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. [A.31] 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. [A.40] 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. OBJECTIVES

Encouraging the use of AISI 2136 Stavex due to its good weldability, resistance against corrosion & chemicals, good machinability, and good heat resistance. Finding out the best suitable tool material for machining AISI 2136 Stavex depending upon requirements such as Overcut, MRR, TWR which directly affects quality of machining and machining time.

5. 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 2136 Stavex

Electrode to be used- Copper & Brass both of have 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- 2 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 2136 Stavex

Material	C	Cr	Fe	Mn	Ni	P	S	Si	N
AISI2136 Stavex 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 2136 Stavex 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 Brass: It is easily availably and can be readily machined.Useful for machining some titanium alloy under poor chip removal conditions. Wear ratio for brass is between 1 and 6 which can be tolerated when drilling small diameter hole.[B.2].

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 [B.2].

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

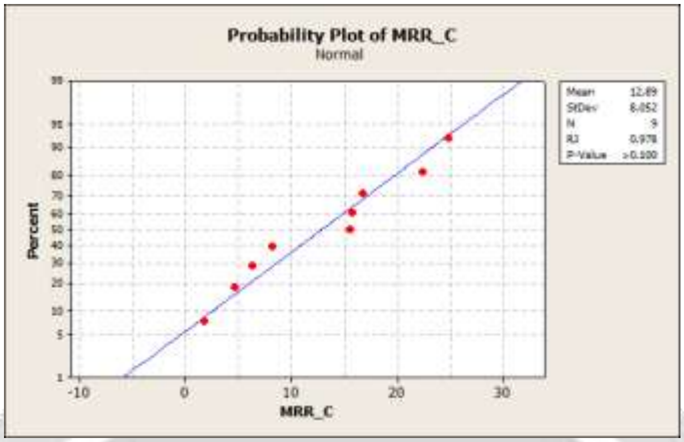
6. EXPERIMENTAL RESULT & ANALYSIS

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.

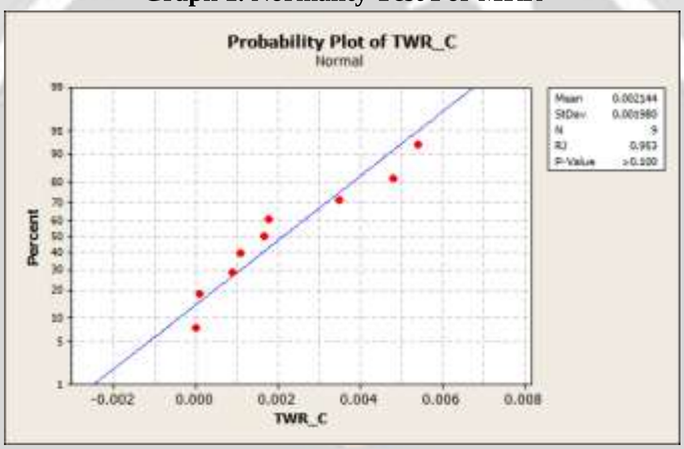
Table 3. Design Layout and Experimental Results

Run No.	Current (Amps)	Pulse on Time (µs)	Pulse off Time (µs)	Overcut (mm) Copper Tool	Overcut (mm) Brass Tool	MRR (mm3/min) Copper Tool	MRR (mm3/min) Brass Tool	TWR (mm/min) Copper Tool	TWR (mm/min) Brass Tool
1.	4	5	4	0.15	0.17	6.33	7.47	0.000890	0.000988
2.	4	6	5	0.16	0.22	4.68	10.40	0.000101	0.001990
3.	4	7	6	0.17	0.18	1.72	4.97	0.000025	0.000310
4.	8	5	5	0.22	0.26	15.54	21.98	0.001086	0.006120
5.	8	6	6	0.24	0.27	16.67	36.45	0.001670	0.009470
6.	8	7	4	0.24	0.30	8.17	30.90	0.001797	0.009960
7.	15	5	6	0.26	0.31	22.39	39.17	0.004807	0.017200
8.	15	6	4	0.29	0.32	24.80	46.52	0.005424	0.035500
9.	15	7	5	0.32	0.36	15.68	62.08	0.003496	0.031490

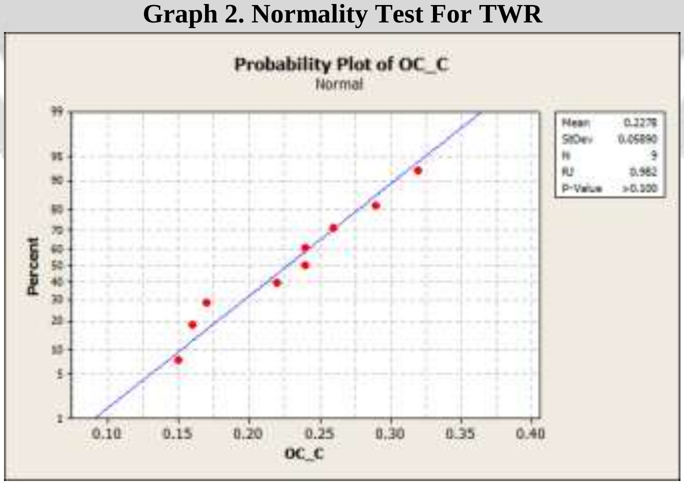
6.1 Normality Testing For Copper as a Tool Material



Graph 1. Normality Test For MRR



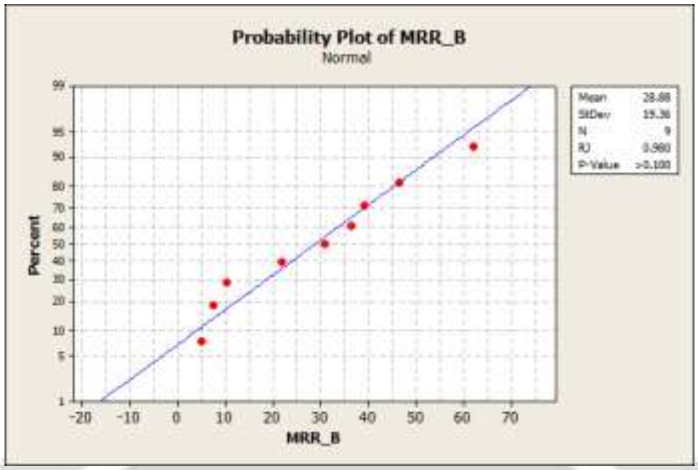
Graph 2. Normality Test For TWR



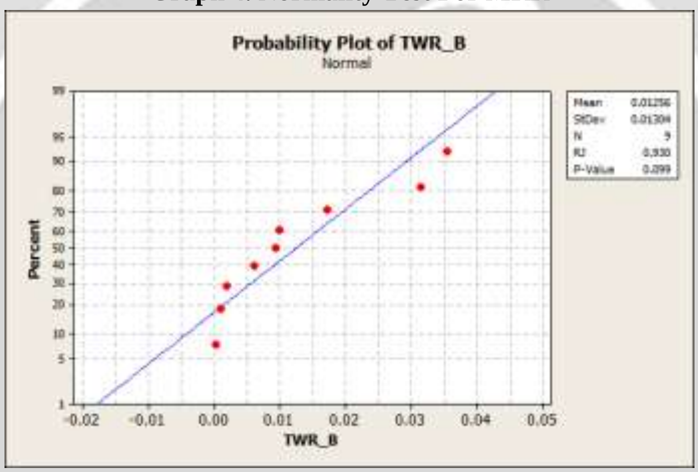
Graph 3. Normality Test For OC

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.

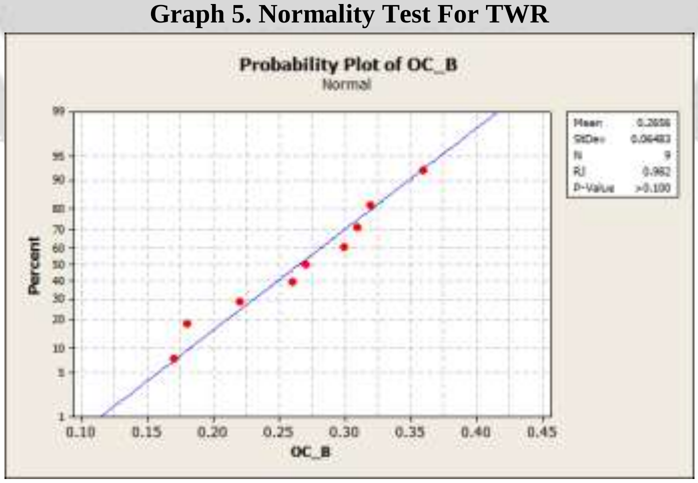
6.2 Normality Testing For Brass as a Tool Material



Graph 4. Normality Test For MRR



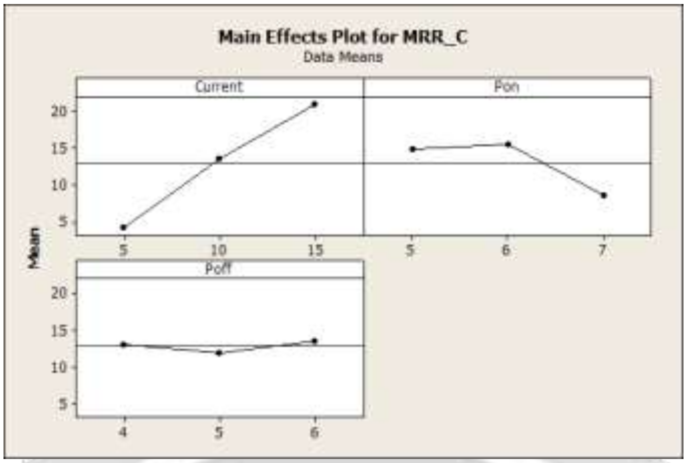
Graph 5. Normality Test For TWR



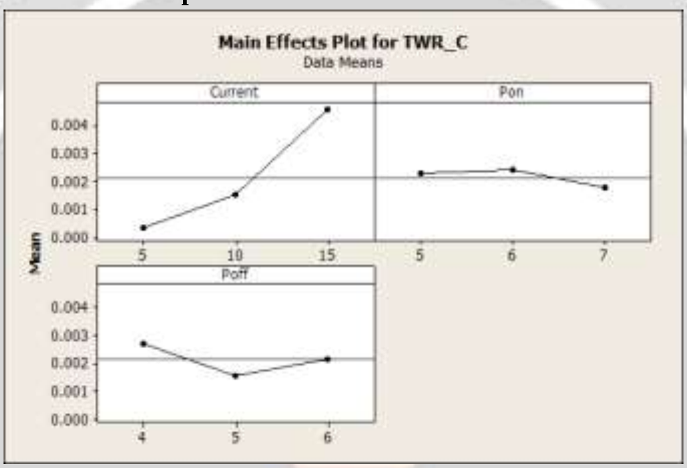
Graph 6. Normality Test For OC

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.

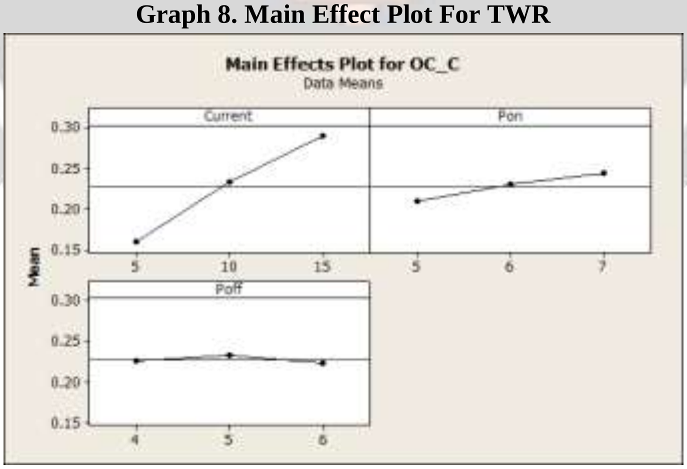
6.3 Main Effect Plot For Copper as a Tool Material



Graph 7. Main Effect Plot For MRR



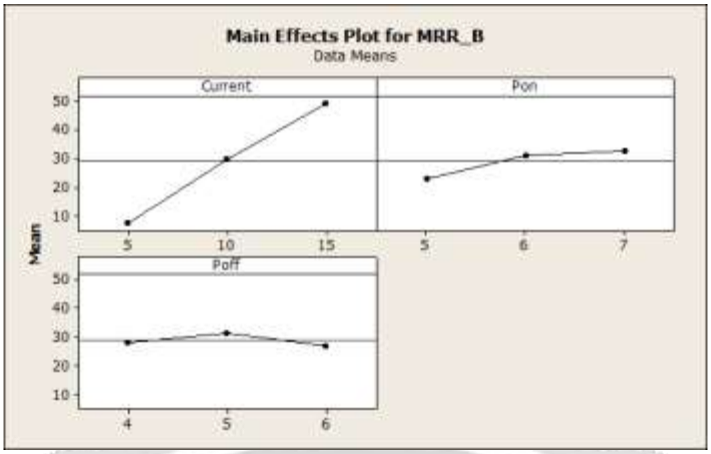
Graph 8. Main Effect Plot For TWR



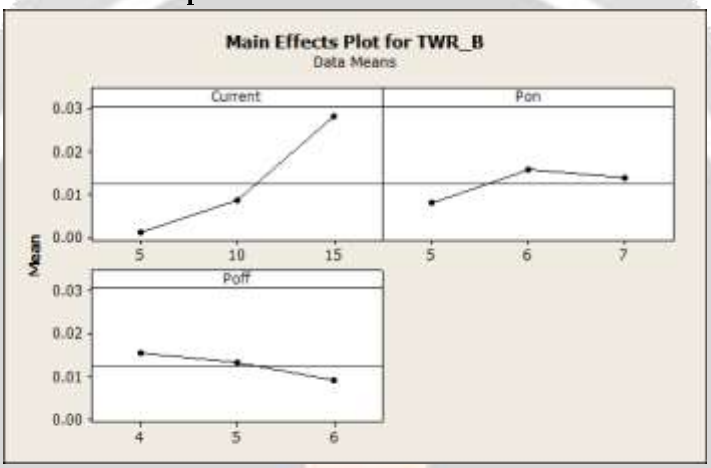
Graph 9. Main Effect Plot For OC

Graphs shows the main effect plot of process parameters on overcut at different parameters like current, pulse on time, pulse off time in EDM process of machining for Stavex by Copper tool.

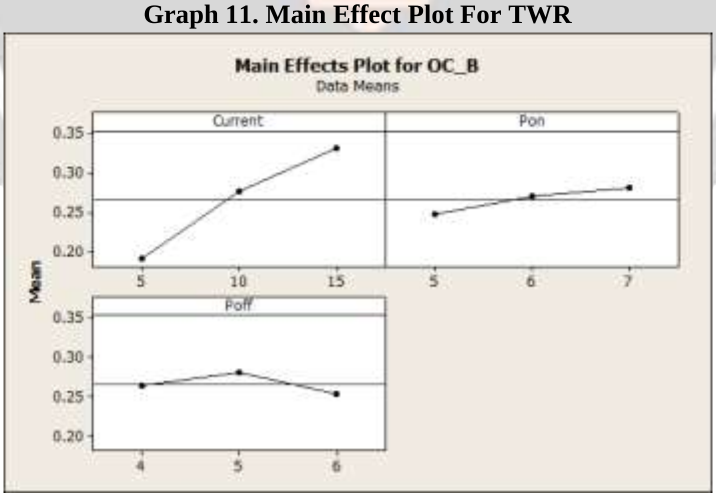
6.4 Main Effect Plot For Brass as a Tool Material



Graph 10. Main Effect Plot For MRR



Graph 11. Main Effect Plot For TWR



Graph 12. Main Effect Plot For OC

Graphs shows the main effect plot of process parameters on overcut at different parameters like current, pulse on time, pulse off time in EDM process of machining for Stavex by Brass tool.

6.5 Regression Model Analysis

Regression Model analysis for Overcut (OC) (Copper Tool)
The Regression equation is : OC = **0.0061 + 0.0130 Current + 0.0167 Pon - 0.00167 Poff**

Table 4. Analysis of Variance OC (Copper Tool)

Source	P
Regression	0.000
R-Sq = 97.4%	R-Sq(adj) = 95.8%

Regression Model analysis for Overcut (OC) (Brass Tool)
The Regression equation is : OC = **0.0506 + 0.0140 Current + 0.0167 Pon - 0.00500 Poff**

Table 5. Analysis of Variance OC (Brass Tool)

Source	P
Regression	0.003
R-Sq = 92.6%	R-Sq(adj) = 88.6%

Regression Model analysis for Material Removal Rate (MRR) (Copper Tool)
The Regression equation is : MRR = **13.6 + 1.67 Current - 3.11 Pon + 0.25 Poff**

Table 6. Analysis of Variance MRR (Copper Tool)

Source	P
Regression	0.003
R-Sq = 92.1%	R-Sq(adj) = 87.3%

Regression Model analysis for Material Removal Rate (MRR) (Brass Tool)
The Regression equation is : MRR = **- 38.5 + 4.16 Current + 4.89 Pon - 0.72 Poff**

Table 7. Analysis of Variance MRR (Brass Tool)

Source	P
Regression	0.004
R-Sq = 91.6%	R-Sq(adj) = 86.6%

Regression Model analysis for Material Removal Rate (MRR) (Brass Tool)

The Regression equation is : MRR = **- 38.5 + 4.16 Current + 4.89 Pon - 0.72 Poff**

Table 8. Analysis of Variance MRR (Brass Tool)

Source	P
Regression	0.004
R-Sq = 91.6%	R-Sq(adj) = 86.6%

Regression Model analysis for Tool Wear Rate (TWR) (Brass Tool)

The Regression equation is : TWR = **- 0.0156 + 0.00270 Current + 0.00291 Pon - 0.00324 Poff**

Table 9. Analysis of Variance TWR (Brass Tool)

Source	P
Regression	0.009
R-Sq = 88.6%	R-Sq(adj) = 81.8%

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.

6.6 Optimization using Comparison of Taguchi Method & Regression Analysis

Table 10. Optimized Value

Optimum Output	Current	Pulse on Time	Pulse off Time	Validation From Experiments
MRR_C	15	6	6	26.66
TWR_C	5	7	5	0.0001
OC_C	5	5	6	0.14
MRR_B	15	7	5	64.4
TWR_B	5	5	6	0.0002
OC_B	5	5	6	0.16

7. CONCLUSION

Effect of process parameters on Overcut for Copper tool was concluded as under :

- Effect of Current : Overcut is increase with the increase in Current.
- Effect of Pulse on Time : Overcut is increase with the increase in Pulse on Time.
- Effect of Pulse off Time : Overcut is a slight decrease with the increase in Pulse off Time.

Effect of process parameters on Overcut for Brass tool was concluded as under :

- Effect of Current : Overcut is increase with the increase in Current.
- Effect of Pulse on Time : Overcut is increase with the increase in Pulse on Time.

- Effect of Pulse off Time : Overcut is decrease with the increase in Pulse off Time.

Effect of process parameters on MRR for Copper tool was concluded as under :

- Effect of Current : MRR is increase with the increase in Current.
- Effect of Pulse on Time : MRR is decrease with the increase in Pulse on Time.
- Effect of Pulse off Time : MRR is a slight increase with the increase in Pulse off Time.

Effect of process parameters on MRR for Brass tool was concluded as under :

- Effect of Current : MRR is increase with the increase in Current.
- Effect of Pulse on Time : MRR is increase with the increase in Pulse on Time.
- Effect of Pulse off Time : MRR is a slightly decrease with the increase in Pulse off Time.

Effect of process parameters on TWR for Copper tool was concluded as under :

- Effect of Current : TWR is increase with the increase in Current.
- Effect of Pulse on Time : TWR is decrease with the increase in Pulse on Time.
- Effect of Pulse off Time : TWR is increase with the increase in Pulse off Time.

Effect of process parameters on TWR for Brass tool was concluded as under :

- Effect of Current : TWR is increase with the increase in Current.
- Effect of Pulse on Time : TWR is decrease with the increase in Pulse on Time.
- Effect of Pulse off Time : TWR is slightly decrease with the increase in Pulse off Time.

8. 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 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.

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