# “INVESTIGATION OF MRR, TWR AND RADIAL OVERCUT AT VARYING DEPTH OF MACHINING DURING DIE SINKING EDM”

**A Thesis Submitted**

**In Partial Fulfillment of the Requirements**

**For the Degree of**

## MASTER OF TECHNOLOGY

**In**

**PRODUCTION AND INDUSTRIAL ENGINEERING**

**By**

**GULSHAN KUMAR**

**Enrollment No: -** 1800103228

**Under the Supervision of**

**Mrs. Sumita Chaturvedi**

**DEPARTMENT OF MECHANICAL ENGINEERING,**

**INTEGRAL UNIVERSITY, LUCKNOW**

**JULY, 2020**

INTEGRAL UNIVERSITY

Lucknow

## CERTIFICATE

This is to certify that the thesis work entitled **"Investigation of MRR, TWR and Radial Overcut at varying depth of machining during Die Sinking EDM"** submitted by GULSHAN KUMAR, **Enrollment No.** 1800103228 in partial fulfillment for the award of **Master of Technology** degree in **Mechanical Engineering Department** with specialization in Production and Industrial Engineering, to Integral University, Lucknow (U.P.). He has carried out his thesis work under my supervision and guidance and to the best of my knowledge; the matter embodied in this thesis has not been submitted to any other University/Institute for award of any degree to the candidate or to anybody else.

Date: 08/09/2020

Mrs. Sumita Chaturvedi
(Assistant Professor)
Department of Mechanical Engineering
Integral University, Lucknow

ii

## ABSTRACT

Electro Discharge Machine is a non-traditional machine used to cut hard alloy materials having high impact resistance and high toughness. It is used to cut complex contours that are impossible to machine by other conventional cutting techniques. The present experimental investigation is conducted on EDM is performed on AISI 4140 or EN-19 as workpiece with copper as electrode (tool) to establish the relationship between process parameters of EDM on material removal rate, tool wear rate and radial overcut. Depth of machining is also considered as a process parameter in this investigation. The investigation concluded that material removal rate, tool wear rate and radial overcut were majorly influenced by the peak current and depth of machining. Pulse on time was found to be the least dominating parameter for all the performance measures.

# ACKNOWLEDGEMENT

I would like to express my deep sense of gratitude and respect to my supervisor **Mrs. Sumita Chaturvedi** for her invaluable guidance, motivation, constant inspiration and above all for her ever co-operating attitude that enabled me in bringing up this thesis in the present form. I consider myself extremely lucky to be able to work under the guidance of such a dynamic personality.

I am also thankful to **Dr. P.K. Bharti**, Head of Department, Mechanical Engineering, for his support and motivation.

I would like to thank to **Dr. K. Kulkarni and Mrs. Samta Samal (SEM Lab Incharge), IIT Kanpur** and my all friends with whose additional help this study has been a succulent one.

I would also like to thank to "Dilawar Engineering Works" who provided me Electro Discharge Machine (EDM) for successful completion of experimental work.

My very special thanks go to all my family members. Their love, affection and patience made this work possible and the blessings and encouragement of my beloved parents greatly helped me in carrying out this research work.

Gulshan

Place: Lucknow — Gulshan Kumar

Date: 08/09/2020



iv

# TABLE OF CONTENTS

CERTIFICATE……….…………………………..………………………….……….………..ii
ABSTRACT……………………….……………………………………….…………iii
ACKNOWLEDGEMENT………….………………………………………….…….............iv
LIST OF TABLES……………….………………………………………………………viii
LIST OF FIGURES……………………………………………...…………………..ix

**CHAPTER 1: INTRODUCTION…………………………………………………......1-9**
1.1 Principle of EDM ……………………………………………………………...1
1.2 EDM Process……………………………………………………………………...2
1.3 Dielectric fluid…. ……………………………………………………………..3
1.4 Servo Mechanism …………………………………………………………...3
1.5 Parameters of EDM…………………………………………………………5
1.6 Advantages of EDM……………………………………………………………7
1.7 Disadvantages of EDM…………………………………………….............7
1.8 Applications of EDM…………………………………………………………8
1.8.1 Prototype Production……………………………………………………….8
1.8.2 Coinage Dies Making..……………………………………………………….8
1.8.3 Small Hole Drilling…..………………………………………………………8

**CHAPTER 2: LITRETURE REVIEW ………………………………………..10-15**
2.1 Literature Review…………………………………………………………10
2.2 Problem Formulation……………………………………………………...15

**CHAPTER 3: TAGUCHI APPROCH AND ANOVA…………………………..16-20**

3.1 Taguchi method…………………..……..…………………………………….…………16
3.2 Application of S/N ratio…………………………………………………………..18
3.3 Advantages of S/N ratio over average………………………………………19
3.4 Role of ANOVA…………………………………………………………………...19
3.5 Analysis of variance ……..………..…………………………………………....19
3.6 Table for Taguchi Design of experiments..…………………………………....20

**CHAPTER 4: EXPERIMENTATION…………………………………………….21-30**
4.1 Experiment setup…………………………………………………………….21
4.2 Dielectric Fluid…………………………………………………………………24
4.3 Work piece material……………………………………………………………25
4.4 Tool material………………………………………………………...……..…26
4.5 Material removal rate…………………………………………………………..27
4.6Tool wear rate…………………………………………………………………..27
4.7 Weight Measurement..…………………………………………………………28
4.8 Radial Overcut…..………………………………………………………………30

**CHAPTER 5: RESULTS AND DISCUSSION………………………….…………….31-48**
5.1 Calculation for MRR………………………………………………….…..31
5.1.1 Calculation of S/N ratio for MRR……………..…………………….32
5.1.2 Calculation of Mean S/N ratio for MRR..……..…………………….33
5.1.3 ANOVA for MRR………………..……………..…………………….34
5.2 Calculation for Tool wear rate……….……………………………….......36
5.2.1 Calculation of S/N ratio for TWR……………..…………………….37
5.2.2 Calculation of Mean S/N ratio for TWR..……..…………………….38
5.2.3 ANOVA for TWR………………..……………..…………………….38
5.3 Calculation for Radial Overcut……………………….……………….………40

5.3.1 Calculation of S/N ratio for Radial Overcut …………………….. 41
5.3.2 Calculation of Mean S/N ratio for Radial Overcut ………...…. 42
5.3.3 ANOVA for Radial Overcut ……………………………………… .43
5.4 Confirmation Test…………………………………………………………… .47

**CHAPTER 6: CONCLUSION……………………………………………….. 49-50**
6.1 Conclusion……………………………………………………………. . 49

**CHAPTER 7: REFERENCES……………………………………………… 51-54**

# LIST OF TABLES

**CHAPTER 3**

Table-3.1 Process parameters and there levels.

Table-3.2 Experiment L9 orthogonal Array.

**CHAPTER 4**

Table-4.1 Technical specification of EDM

Table-4.2 Chemical composition of Work-piece (EN-19) by weight

Table 4.3 Properties of EN-19

**CHAPTER 5**

Table-5.1 Calculation of Material Removal Rate for EN-19

Table-5.2 Calculation of S/N ratio for Material Removal Rate

Table-5.3 Calculation of mean S/N ratio for Material Removal Rate

Table-5.4 ANOVA of Material Removal Rate

Table-5.5 Calculation for Tool wear rate.

Table-5.6 Calculation of S/N ratio for Tool wear rate.

Table-5.7 Calculation of Mean S/N ratio for Tool wear rate.

Table-5.8 ANOVA of Tool wear rate.

Table-5.9 Calculation of Radial Overcut.

Table-5.10 Calculation of S/N ratio for Radial Overcut.

Table-5.11 Calculation of Mean S/N Ratio for Radial Overcut.

Table-5.12 ANOVA of Radial Overcut

Table-5.13 Confirmation of expected and actual values of Material Removal Rate.

Table-5.14 Confirmation of expected and actual values of Tool Wear Rate.

Table-5.15 Confirmation of expected and actual values of Radial Overcut.

# LIST OF FIGURES


**CHAPTER 1**

Figure 1.1Description of EDM process

Figure 1.2 Die Sinking EDM

Figure 1.3 Set up EDM for Experiment

**CHAPTER 4**

Figure 4.1 Machining of work-piece on EDM

Figure 4.2 Spark during low level of EDM parameters

Figure 4.3 EDM machine panel showing parameters

Figure 4.4 Sparks produced during EDM

Figure 4.5 EN-19 machined workpieces

Figure 4.6 A single Copper Tools

Figure 4.7 Measuring of workpiece weight

Figure 4.8 Tool and workpiece with digital weight measuring instrument

Figure 4.9 Specifications of digital weight measuring instrument

Figure 4.10 Carl Ziess EVO SEM

**CHAPTER 5**

Figure 5.1 Main effect plot for Material Removal Rate

Figure 5.2: Interaction plot for Material Removal Rate

Figure 5.3: Main effect plot for Tool Wear Rate

Figure 5.4: Interaction plot for Tool Wear Rate

Figure 5.5: Main effect plot for Radial Overcut

Figure 5.6: Interaction plot for Radial Overcut

Figure 5.7: SEM of Sample 1

Figure 5.8: SEM of Sample 4
Figure 5.9: SEM of Sample 7

# 1

# INTRODUCTION

## 1.1 Principles of EDM

Electrical Discharge Machining (EDM) is a controlled material removal technique used to remove metal by means of spark erosion. This process utilizes an electric spark as the cutting tool to machine the workpiece to produce the finished product to the desired size and shape. The material removal process is performed in dielectric medium to enhance the efficiency of the process and applies a pulsating (ON/OFF) electrical charge of high-frequency current by the electrode on to the workpiece. This removes a very tiny layer of metal from the workpiece at a controlled rate.

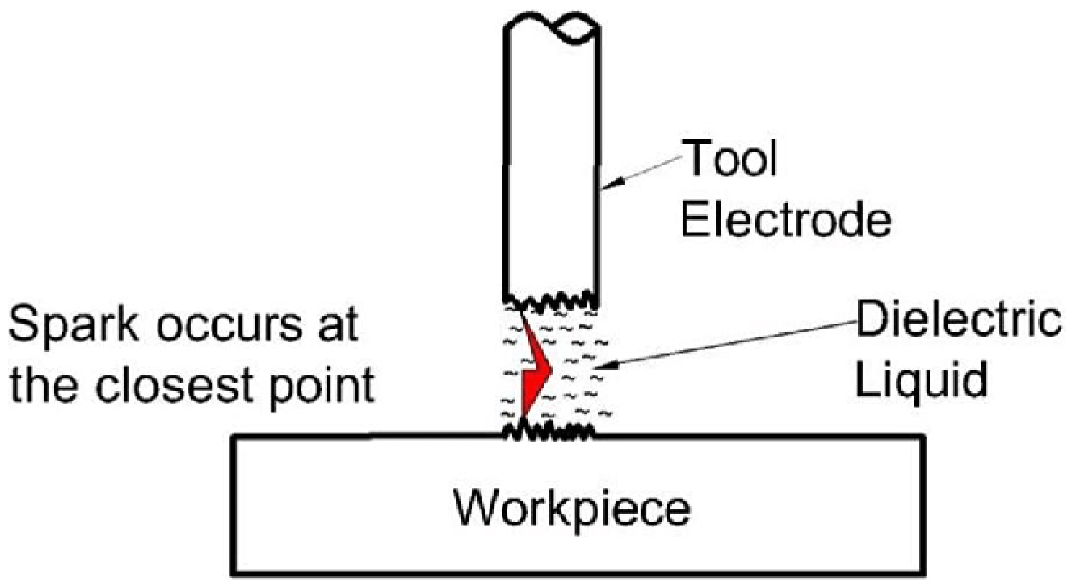


**Figure 1.1 Description of EDM process**

### 1.2 EDM Process

EDM spark erosion is similar to have an electrical short which burns a hole in a piece of material it is in contacts. In the EDM process, both the work material and the electrode material must be electrically conductive.

The EDM process is used in two different ways:

1. A pre-shaped electrode or a tool, usually graphite or copper, is in shape of a cavity to be produced on workpiece which is fed vertically downwards and erodes the workpiece into finished desired product.

2. A continuously travelling vertical electrode in form of wire of a diameter of about a small needle, controlled by the servomechanism which follow a programmed path to machine or cut a narrow slot into the workpiece and produces the required shape.

#### 1.2.1 Conventional EDM

In the EDM process, continuous electric sparks are produced to machine the workpiece, which acquires the shape opposite to that of the cutting electrode. The electrode and the workpiece are both submerged in a dielectric fluid to make the process more effective. A servomechanism is used to maintain a gap of low thickness between the tool and the work, preventing them from contacting each other. This is called spark gap.

In EDM die-sink machining, a relatively soft copper or graphite electrode is used to machine hard material. The EDM process produces a cavity which is slightly larger than the size of electrode because of the overcut or enlargement.

#### 1.2.2 Wire-Cut EDM

The wire-cut EDM is a electro discharge machine which uses electrode in form of wire to produce the desired contour or shape. It do not require a special shaped electrode, but it uses a continuously traveling vertical electrode in form of wire under tension as the electrode. The electrode in Wire-EDM is about a thickness as minimum as a diameter needle which produces the shape required.

### 1.3 Dielectric Fluids - Conventional EDM

During the process EDM, the work-piece and the electrode are submerged in the dielectric fluid, which is an electrical insulator that provides a medium for controlled discharge of sparks. The dielectric fluid provides a means of flushing when pumped through the spark gap. This removes suspended debris particles of workpiece material and electrode from the spark gap.

### 1.4 The Servo Mechanism

Both wire cut EDM and die-sinking EDM machines are equipped with a servo control mechanism which automatically maintains a constant spark gap between the tool and the workpiece. It is an important aspect for both machine types that there is no physical contact between the electrode and the workpiece, otherwise sparking may damage the workpiece and the wire could break. The servomechanism serves the purpose of advancing the electrode into the workpiece as the operation progresses and also senses the work-tool gap and controls it to maintain a proper spark gap which is necessary for a successful machining operation.

EDM Machine usually have the following components:

(1) **Bed and Column** – It is the base bed and column structure, that ensures that the electrode and the table, between the position of the workpiece. The level of position accuracy has a straight impact on the machining. If the machine's accuracy is not high, the machining accuracy is not guaranteed. Hence, not only the structure of bed and column should be stiff, weight-bearing spindle but also can reduce the deformation caused by temperature changes.

(2) **Table** - Table is used mainly to support and for clamping the workpiece. By turning the screw, changes can be done in the vertical and horizontal relative position of the electrode and the workpiece. The tank is equipped with a work bench so as to accommodate the dielectric fluid, soaking the electrode and the larger workpiece in the dielectric fluid, playing cooling, chip removing effect. Clamping table changes the vertical and horizontal position of the electrode and the workpiece to achieve the desired position.

(3) **Spindle head** -EDM spindle head is an important component of EDM machine. The spindle head requirements are as follows:

i) An appropriate degree of axial and lateral accuracy and stiffness;

ii) Enough feed and speed;

iii) Linear axis movement of spindle with anti-reverse performance;

iv) Have high sensitivity;

v) Reasonable quality of the bearing capacity of the electrode.

(4) **EDM machine tools dielectric fluid and there circulating filtration system**

The roles of the dielectric fluid are as follows:

a) The dielectric fluid provides a medium for spark to travel in the spark gap between the tool (electrode) and the workpiece.

b) Removing the debris after material removal by flushing of dielectric in the spark gap.

c) Serves the purpose of cooling and reducing tool electrode surface discharge generated by the instantaneous local temperature, else the surface will be produced due to local overheating and the formation of spark discharge.

(5) **EDM pulse power machine -** Pulse-frequency alternating current is used to supply spark discharge gap into the energy needed to erode the metal from the surface of workpiece. EDM pulse power influences the productivity, surface quality, working speed, work stability and electrode wear and tear and other technical and economic indicators.

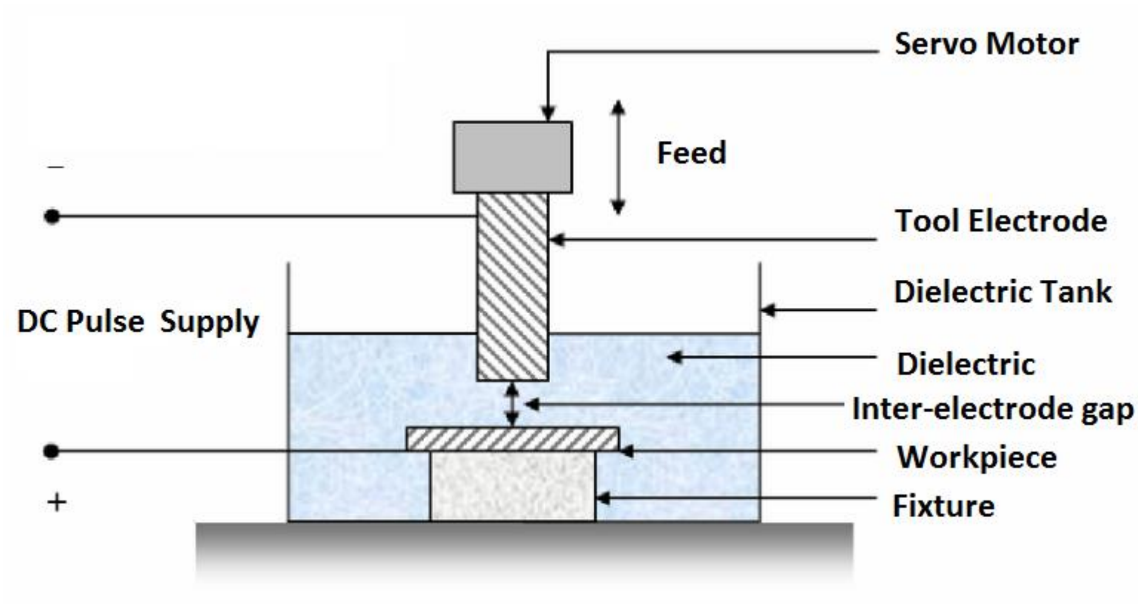


**Figure 1.2. Die Sinking EDM**

### 1.5 Parameters of EDM

The parameters of EDM are mainly classified into following two categories

1) The process parameters
2) The performance parameters

#### 1.5.1 The process parameters

The EDM process parameters are used to control and optimize the performance measures of the machining process. These process factors are controllable machining input parameters that determines the condition in which machining is undergone. These controlling parameters are mainly divided into two types. They are Electrical and Non-electrical parameters.

**A. Electrical Parameters**

**a) Polarity:** The polarity can be negative or positive. Usually MRR is highest when the tool is connected to positive polarity.

**b) Discharge voltage:** The voltage is produced between the Work-piece and Tool when a DC power supply is provided to the circuit.

**c) Gap Voltage:** Gap voltage is classified into open gap voltage and working gap voltage. Open gap voltage is measured at the gap before the spark current discharge begins to flow and working gap voltage can also be calculated at the gap when spark current discharge.

**d) Peak Current:** Peak Current is the major influencing parameter in EDM machining for various performance measures. It is the amount of power used in EDM. MRR majorly depends on peak current and peak current is directly proportional to material removal rate.

**e) Pulse on Time:** It is the period of time for which current is allowed to flow per cycle. Increase pulse on time increases the machining rate. By increasing pulse on time the material removal rate increases but poor surface finish is achieved.

**f) Pulse off time:** The period of time (μs) between the two consecutive sparks. This time allows the removed molten material to solidify and to wash out them of the arc gap. This parameter affects the speed and the stability of machining. Thus, if the pulse-off-time is too short, it will cause unstable sparks.

**g) Electrode Gap:** It is the distance between the Tool and Work-piece during machining in the process of EDM. Servo mechanism provides a constant gap between the tool and the workpiece.

h**) Duty Factor:** Duty Factor is the percentage of ratio between pulse duration and total cycle time.

Duty Factor (%) = [Ton (μs)/Total Cycle Time (μs)] x 100

**B. Non-Electrical Parameters**

**a) Work piece material:** The type of workpiece material is one of the major non-electrical parameters that influence the performance characteristics of EDM. There are many materials such as stainless steels, die materials, alloys, super alloys and titanium alloys that are very hard to cut.

**b) Electrode material:** Basically tool materials are classified as metallic, non-metallic and combination of metallic and non-metallic materials. Normally Copper, Brass, Graphite, Copper-Tungsten, Silver Tungsten, Copper Graphite and Tungsten Carbide are used as a tool material in EDM which provide better conductivity, good resistance and wearing capacity.

**c) Electrode shape:** The performance characteristics mainly depend upon the shape of the tool. Basic shapes of electrode used are Rectangular, Square, Cylindrical, Hexagonal and Circular.

**d) Dielectric:** Dielectric provides a medium that acts as an insulator medium and doesn‘t conduct electricity and is used to flush the eroded particles. It cools region, tool and work material. Paraffin, White Spirit, Kerosene, deionized water, hydrocarbon Fluids and transformer oil are the different EDM dielectric fluids.

### 1.5.2 Performance parameters

A majority of papers have focused on yielding the optimal EDM performance measures for higher Material Removal Rate, lower Tool Wear Rate and lower Surface Roughness. The present section provides a detailed study into each of the performance measures and provides the methods for their enhancement.

**a) Material Removal Rate:** MRR is a performance measure for the removal rate of the work material and is typically used to quantify the rate at which machining of work is carried out. It is expressed as volumetric amount of work material removed per unit time.

**b) Tool Wear Rate:** TWR is a performance measure for the removal rate of the tool and is a parameter that is taken into account while considering the geometrical accuracy of the machined surface. It is expressed as the volumetric amount of tool material removed per unit time.

**c) Surface Roughness:** Surface roughness is an important output performance in EDM which influences the quality of product and its cost. Surface roughness is measured by a surface roughness tester (optical or stylus).

**d) Hole Enlargement:** An EDM cavity machined is always larger in size than the electrode used to machine it. The difference in the size of the electrode and the size of the cavity (or hole) machined by EDM is called as the overcut.

**e) Recast layer thickness:** The recast layer refers to the area of re-solidified molten material occurring at the topmost layer of the machined surface. It is usually located above the heat affected zone.

## 1.6 Advantages of EDM

Conventional EDM machines can be programmed for vertical machining, orbital, vectorial, directional, helical, conical, rotational, spin and indexing machining cycles. Hence these versatility gives Electrical Discharge Machines many advantages over conventional machine processes.

• Electrically conductive can be easily cut using the EDM process.

• Hard workpieces can be easily machined and eliminates the deformation caused by heat treatment.

• Complex dies sections and molds can be easily produced with accuracy, in less time, and at lower costs.

• It is a burr-free process.

• Can machine thin fragile sections such as webs or fins without deforming the part.

## 1.7 Disadvantages of EDM

- Material removal is slow.
- Difficult to reproducing sharp corners on the work piece due to electrode wear.
- High specific power consumption.
- High power consumption.
- “Overcut” is formed.

- Excessive tool wear is observed during machining.
- Can machine electrically non-conductive materials with specific setup of process.
- The additional time and cost used for creating electrodes for sinker EDM.
- Potential fire hazards associated with use of combustible oil based dielectrics.

## 1.8 Applications of EDM

### 1.8.1 Prototype Production

The EDM process is a most widely used by the mould making process indie industries, but it is becoming a common method of making prototype and production parts, especially in the aerospace, automobile and electronics industries where production quantities are relatively low.

### 1.8.2 Coinage Dies Making

Used for creation of dies, producing jewelries and badges, for blanking and piercing by the coinage process.

### 1.8.3 Small Hole Drilling

Small holes in EDM are used to drill rows of holes into the leading and trailing edges of turbine blades used in jet engine. Gas flow through these small holes allows the engines to use higher temperatures than otherwise possible.

The high temperature, very hard, single crystal alloys employed in these blades makes conventional machining of these holes with high aspect ratio extremely difficult, if not impossible. Small hole EDM is also used to create microscopic orifices for fuel system components.

**Figure 1.3 Setup of EDM for the experiments**

# 2

# LITERATURE REVIEW

## 2.1 Literature Review

Electrical discharge machining (EDM) is the non-contact machining technique has been continuously evolving from a mere manufacturing geometrically complex or hard material parts and die making process to a micro scale application machining alternative attracting a significant amount of research interests. In recent years, EDM researches have explored a number of ways to improve the sparking efficiency including some unique experimental concept that depart from the EDM traditional sparking phenomenon.

A study conducted was by Subramanian Gopalakannan and Thiagarajan Senthilvelan [1] to find the effect of pulsed current on material removal rate, electrode wear, surface roughness and diameteral 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, copper-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.

The study of Pravin R. Kubade and V. S. Jadhav [2] investigated the influence of EDM parameters on EWR, MRR and ROC while machining of AISI D3 material with a copper electrode. The parameters considered were pulse-on time (Ton), peak current (Ip), duty factor (t) and gap voltage (Vg). It is found that the MRR is mainly influenced by peak current where as other factors have very less effect on material removal rate. Electrode wear rate is mainly influenced by peak current and pulse on time, duty cycle and gap voltage has very less effect on electrode wear rate. Peak current has the most influence on radial overcut then followed by duty cycle and pulse on time with almost very less influence by gap voltage.

To study the influence of process parameters and electrode shape configuration on the machining characteristics such as surface quality, material removal rate and electrode wear Shishir Mohan Shrivastava and A.K. Sarathe [3] conducted experiments and found better machining performance was obtained generally with the electrode as the cathode and the work-piece as an anode and it was observe that for high MRR main process parameters are peak current, pulse on time ,pulse off time, whereas for electrode wear were mainly influenced by peak current and pulse on time. Surface quality was mainly influenced by peak current. As far as tool shape configuration concerned best tool shape for higher MRR and lower TWR is circular, followed by square, triangular, rectangular, and diamond cross sections.

In a research, Abhishek Gaikwad, Amit Tiwari, Amit Kumar and Dhananjay Singh [4] studied the effect of control factors (i.e., current, pulse on time, pulse off time, fluid pressure) for maximum material removal rate (MRR) and minimum electrode wear rate (EWR) for EDM of hard material Stainless steel 316 with copper as cutting tool electrode. In this paper both the electrical factors and non electrical factors has been focused which governs MRR and EWR. Paper is based on Design of experiment and optimization of EDM process parameters. The technique used is Taguchi technique which is a statistical decision making tool helps in minimizing the number of experiments and the error associated with it. The research showed that the Pulse off time, Current has significant effect on material removal rate and electrode wear rate respectively.

In an investigation conducted by Y. H. Guu [5] of surface characteristics of Fe-Mn-Al alloy analyzed by means of the atomic force microscopy (AFM) technique and concluded that the higher discharge energy caused more frequent melting expulsions, leads to deep and large crater formation on surface of work, resulting in a poor surface finish.

Another investigation conducted by George et al [6] optimized the machining parameters in the EDM machining of C-C composite using Taguchi method. The process variables affects electrode wear rate and MRR, according to their relative significance, are gap voltage, peak current and pulse on time respectively.

C.H. Cheron [7] machined XW42 tool steel and concluded that material removal rate with Cu electrode is greater than graphite electrode. He also concluded that Cu is suitable for roughing surface while graphite is suitable for finishing surface.

A similar study was conducted by Ahmet Hascalık and Ulas¸Caydas [8] using parameters such as pulse current and pulse duration and concluded that electrode material has an obvious effect on the white layer thickness, the material removal rate, surface roughness and electrode wear are increasing with process parameters.

D. K. Ojha et al [9] conducted analysis with Taguchi approach and revealed that current significantly influences MRR, Dimensional Tolerance and surface roughness whereas TWR is mostly influenced by flow rate of the dielectric fluid used.

M M Sari et al [10] by their experimental investigation foun that carbon nano-tubes give better surface finish as compared to the traditional EDM process. The thickness of recast layer is observed to be smaller when carbon nano-tubes are used. Tool Wear Rate and Material Removal Rate are enhanced and heat can be effectively absorbed by the carbon nano-tubes, if optimum machining parameters are set.

In an investigation conducted by Deepu P.Nair et al [11] conducted an experimental investigation for surface characteristics of M300 Steel and concluded that the parameter current was the most effective for surface roughness followed by the voltage and pulse on time. S. Ben Salem et al [12] conducted experiments and found that a fewer number of experiments is required to optimize the surface roughness and it was found that the current intensity is the major dominating parameter for surface roughness.

In a research conducted by V. Chandrasekaran et al [13] through their investigation revealed that the MRR is highest for all compositions. As the percentage of nickel increases the thermal conductivity of the composition increases since the nickel material is easily removed from the surface of the parent material. Hence the MRR increases with increase in the percentage of nickel. It is also found that the surface roughness increases with current and flushing pressure and doesn't depend on percentage of Ni. The optimum Ra values decreased with increasing electrode rotation. Francesco Modica et al [14] investigation throw light on relation between the material removal technique, identified during the evaluation of MRR and TWR. The selected parameters were voltage, discharge current, pulse width and frequency, so as to experimentally quantify the waste of material produced and optimize the technological process in order to decrease it. Kumar Sandeep [15] investigated surface quality and metal removal rate which are the utmost important factors for selecting the optimum condition of processes and also the economical aspects. The research reported the trend of research in EDM.

Lau et al [16] established the feasibility of using EDM for machining composite of carbon fiber. Parameters selected were currents, pulse durations, tool materials and polarities and it concluded that it is totally feasible for EDM to machine carbon fiber composite. Copper is found to be better than graphite electrodes for tool wear and surface finish. They suggested that positive polarity must be opted for machining carbon fiber composite materials so as to achieve low tool wear ratio.

An experimental investigation carried by Amoljit S Gill et al [17] on EN31with Cu-Cr-Ni Powder Metallurgy Tool found that current is the most contributing parameter towards surface roughness. Navdeep Malhotra et al [18] conducted experiments on EN-31 and found that surface roughness of EN-31 Die Steel was majorly influenced by the current and pulse on time. Lower the value of current better the surface finish and same effect in case of pulse on time.

H.T. Lee [19] found the relationship between the EDM parameters and surface cracks formation on the basis of discharge current and pulse on time parameters for EDM machining of D2 and H13 tool steel and concluded that surface roughness increases when pulse on time and pulse current increases. He also found that increased pulse-on duration will increase both the average white layer thickness and also the induced stress which promote crack formation. Rajesha S et al [20] studied surface roughness on AL-7075 metal matrix composite and concluded that the Surface Roughness initially increases rapidly with an increase in pulse off-time and decreases at a slower pace with increase in level of pulse off time.

Harpuneet Singh [21] Investigating the Effect of Copper Chromium and Aluminum Electrodes on EN-31 Die Steel and concluded that Metal removal rate is better for copper chromium except at 6A current when compared to brass electrode. Maximum MRR was achieved at 12A for both brass and copper chromium.

Gurtej Singh et al [22] through their study found that the negative polarity of tool is esential for minimizing the surface roughness and increasing the pulse on time produces more rough surfaces. Addition of powder particles in dielectric fluid will decreases the level surface roughness of EDMed specimen while higher peak currents offers more rough surfaces.

Khalid Hussain Syed et al [23] studied the performance of EDM using aluminium powder suspended distilled water and concluded that the polarity plays an important role in EDM. Higher productivity is achieved with positive polarity, while better surface finish is obtained in negative polarity. Therefore for rough machining we prefer positive polarity and we also achieve higher MRR. They also concluded that the experimental results prove that distilled water can be used as dielectric fluid instead of hydrocarbon oil and moreover the performance can be improved considerably by the addition of aluminum powder.

Banh Tien Long et al [24] carried the study for Copper and Graphite Electrodes in PMEDM of SKD61 Steel concluded that the reverse polarity gives higher productivity than straight polarity. The Titanium powder mixed in the dielectric fluid at suitable concentration improves the dissection productivity of the material, increases surface quality and surface machining, and reduces electrode erosion. This enhances the productivity and accuracy, and reduces part machining time. Titanium powder mixed in the dielectric fluid increases MRR.

Sushil Kumar Choudhary et al [25] conducted study on current research trend of EDM and concluded that majority of work is being performed to find the effect of process parameters on MRR, TWR and surface quality. PR Dewan [26] studied the latest trends in EDM and concluded about the effect of process parameters on MRR, TWR and surface roughness with various aspects. Shaaz Abulais [27] also studied the current research trends of EDM where he studied the effect of process parameters on performance measures which were conducted by different researchers.

In a research carried out by A.K.M. Asif Iqbal and Ahsan Ali Khan [28] on Stainless steel AISI 304 as work material with copper electrodes showed that voltage and rotary speed of electrode significantly affect various procedures of surface integrity, rotation of tool helped to minimize micro cracks, recast layer thickness and the migration of material became less when rotary tool is used.

Annamalai et al [29]in his research work on material removal rate and surface roughness while machining AISI 4340 in EDM concluded that the increase in peak current increases the material removal rate significantly. When pulse on time increases the material removal rate also increase and there is no much influence when pulse off time is increased.

## 2.2 Problem Formulation

On the basis of above literature review, parameters such as peak current (Ip), pulse on time (Ton) and depth of machining are selected for this thesis work so as to analyze the material removal rate, tool wear rate and radial overcut using Taguchi L9 orthogonal array. Following are the problems that will be covered in this research work:

(i) To analyze the influence of machining parameters and depth of machining on Material Removal Rate.

(ii) To analyze the influence of machining parameters and depth of machining on Tool Wear Rate.

(iii) To analyze the influence of machining parameters and depth of machining on Radial Overcut.

# 3

# TAGUCHI APPROACH AND ANOVA

## 3.1 Taguchi Method

Taguchi has generated a methodology for the application of designing of experiments, which includes a practitioner's handbook. This methodology has taken the experiment design from the world of statistician and is applied fully into the world of manufacturing. This contribution have made the work much simpler by making the use of only fewer experimental designs, and providing a better understanding of the variations and the economic consequences of better quality engineering in the world of production. He introduced his approach using the experimental design for:

- Designing the products and processes which are robust to environmental conditions;
- Designing and developing products and processes which are robust to component variation;
- To minimizing variation about a target value, this philosophy of Taguchi is applicable. He proposed that optimizing engineering process or product should be carried out in three step procedure; they are the design of system, parameter design and tolerance design. In system design the engineer applies scientific engineering knowledge to produce a basic functional prototype design. During the stage of product design stage, the selection of the work materials, components, parameter values etc. are involved. Since system design is an initial step, functional design may be far from optimum in terms of quality and cost.

The objective of parameter design is to optimize the setting of process parameter value for improving performance characteristics and to identify the product parameter values under the optimal process parameter values. Also it is expected that the optimum level of process parameters obtained by the parameter design are insensitive to the varying environmental conditions and other noise factors. Hence the parameter design plays a key role in Taguchi approach for achieving high quality without increasing cost. To solve the problem, Taguchi approach utilizes a special design of orthogonal arrays for studying the entire parameter space using small number of experiments. Loss function is afterwards defined so as to find the deviation between the desired values and experimental values. The value of this loss function is then transformed into a signal-to-noise ratio. Basically there are three category of performance characteristic during the analysis of the signal to noise ratio, they are the lower-the-better, the nominal-the-better, and the higher-the–better. The S/N ratio for each level of process parameter is computer based on the S/N analysis. Larger S/N ratio basically are corresponding to the better performance characteristic and hence the optimal level of the process parameter is the level having the highest S/N and ANOVA analysis, the optimum process parameters can be predicted. Finally, a confirmation test experiment is conducted to verify the experimental optimal set of process parameters obtained from the parameter design. The Taguchi method is adopted to obtain optimal machining performance in the die sinking.

1. **Larger is better (maximum) :** $S/N_{LB} = -10 \log \left( (1/n) \Sigma (1/y_i^2) \right)$

2. **Smaller is better (minimum) :** $S/N_{SB} = -10 \log \left( (1/n) \Sigma y_i^2 \right)$

Where, n is the number of observations or repetitions of a trial and y is the observed data.

The S/N ratios are basically expressed on a decibel scale. We would use S/NT for reducing the objective around a specific target, S/NL when the response is as large as possible, and S/NS when the response is as small as possible. Factor level that optimizes the appropriate S/N ratio is optimal.

The following steps are undertaken while using parameter design of the Taguchi method for optimizing a process with multiple performance characteristics:

- Identifying the performance characteristics and then selecting the process parameters to be evaluated.
- Determine the number of levels for the process parameters and possible interactions between the process parameters.
- Selecting appropriate taguchi orthogonal array and assigning the process parameters to the orthogonal array.

- Conducting the experiments on the basis of the orthogonal array.
- Analyzing the experimental results by using signal to noise ratio and ANOVA.
- Selecting the optimal level of process parameters by the S/N ratio and ANOVA.
- Verifying the optimum level process parameters by conducting confirmation experiment.

### 3.2 Application of S/N Ratio

The change in the product's quality characteristics which is under investigation, in response to a factor introduced in design of experiment is basically the signal of desired effect. Although, when experiments are conducted, there may be numerous external parameters which are not designed into the experiment and may influence the outcome of the experiments. Usually the noise factors are these external factors and their effect on the results of the quality characteristic under experiment is known as noise. The signal to noise ratio is the source of measuring the sensitivity of the quality characteristic which is investigated in a controlled environment, to those external dominating factors (known as noise factors) which are not under control. The concept of S/N ratio was originated in the electrical engineering field. Taguchi effectively applied this theory to achieve the optimum level of parameters from the experiments.

The aim of carrying experiments is always to find the highest possible S/N ratio for the result. A higher value of S/N ratio shows that the signal is much high than the random influence of the noise factors. Product design or process operation consistent with highest S/N ratio, always yields the optimum quality with minimum variance.

The S/N ratio is designed to measure the quality characteristics.

The Signal to Noise ratio basically expresses the scatter around a specific target value. Scatter is smaller for larger ratios. Having knowing the S/N ratio value of the samples before and after the experiment, Taguchi's loss function is used for estimating the potential cost saving from the improved product.

### 3.3 Advantage of S/N Ratio over Average

For analyzing the influence of experiments involving multiple runs, the use of signal to noise ratio over standard analysis is preferred. Analysis using the signal to noise ratio will offer the following advantages:

1. It will provide guidance for selecting optimum level parameter based on least scatter around the target and also on the average value close to the target.
2. It will offer objective comparison between two sets of experimental data having variation around target and the deviation of the average data from the target value.

### 3.4 Role of ANOVA

Taguchi replaces full factorial experiment method with a lean, low cost, quicker, partial factorial experiment. Taguchi's design for the partial factorial is based on specially developed OA's. Since the partial experiment is just a sample of the full set of experiment, the analysis of the partial experiment must be included by an analysis of the confidence that must be placed in the results. Analysis of Variance is routinely used that provides a measure of confidence. This technique does not directly analyze the data, but instead determine the variance of the data. The confidence is generally measured from the variance.

This analysis provides the variance for controllable and the noise factors. By understanding the source and magnitude of variance, robust operating conditions can be predicted. This is second benefit of this methodology.

### 3.5 Analysis of Variance (ANOVA)

Sir Ronald Fisher in the 1930's developed this methodology to interpret the results from agricultural experiments. It is not a complicated method but has a lot of mathematics associated with it. ANOVA is a statistically based methodology and an objective decision-making tool for determining and differentiating the average performance of groups of items tested.

### 3.6 Tables for Taguchi Design of Experiment

Tables for Taguchi design of experiment are shown below:

**Table 3.1: Process Parameters and their levels**

| S.No. | Parameters | Units | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|---|
| **1** | Current | A | 3 | 6 | 9 |
| **2** | Pulse-on-time | μsec | 20 | 30 | 40 |
| **3** | Depth of Machining | mm | 0.5 | 0.8 | 1.1 |

**Table 3.2: Experimentation L9 Orthogonal Array**

| S.No. | Ip | Ton | Depth of Machining |
|---|---|---|---|
| **1** | 3 | 20 | 0.5 |
| **2** | 3 | 30 | 0.8 |
| **3** | 3 | 40 | 1.1 |
| **4** | 6 | 20 | 0.8 |
| **5** | 6 | 30 | 1.1 |
| **6** | 6 | 40 | 0.5 |
| **7** | 9 | 20 | 1.1 |
| **8** | 9 | 30 | 0.5 |
| **9** | 9 | 40 | 0.8 |

# 4

# EXPERIMENTATION

## 4.1 Experimental Setup

ELECTRONICA ZNC EDM machine was used for machining the samples. The machine is as shown in the figure below. EDM is a ‘non-traditional’ or ‘non-conventional’ group of machining methods. Ideally, EDM can be as seen as a series of breakdown and restoration of the liquid dielectric in-between the electrodes. EDM uses spark erosion method to remove the material of the workpiece. The machine was available at Dilawar Engineering Works, Lucknow.

**Table 4.1 Technical Specifications of EDM**

| Sr. No. | Specification | Value |
|---|---|---|
| **1** | Model | ZNC |
| **2** | Dielectric Fluid | EDM Oil |
| **3** | Input Power Supply | Three phase AC 415 V,<br>4 wire system, 50 Hz |
| **4** | Electrode used | Copper |
| **5** | H X W X D machine size | 1750 X 1060 X 525 mm |
| **6** | Maximum Load Lift | 750 kg |
| **7** | Pulse on time | 0.5 to 4000 |
| **8** | Pulse frequency | 0.1 to 500 |
| **9** | Main Table Traverse (X,Y) | 1100 X 650 mm |

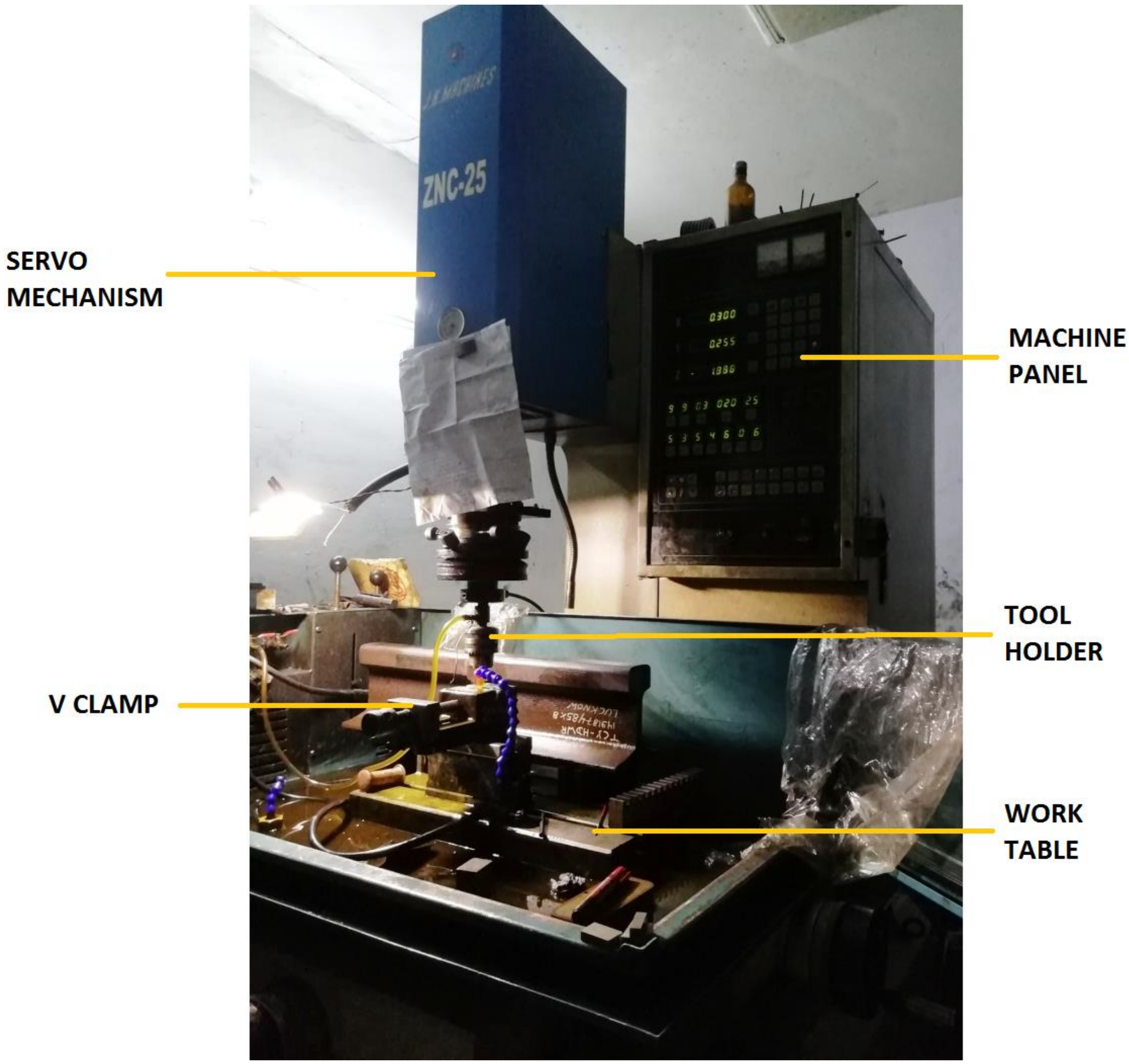


**Figure 4.1: Machining the workpiece on EDM**

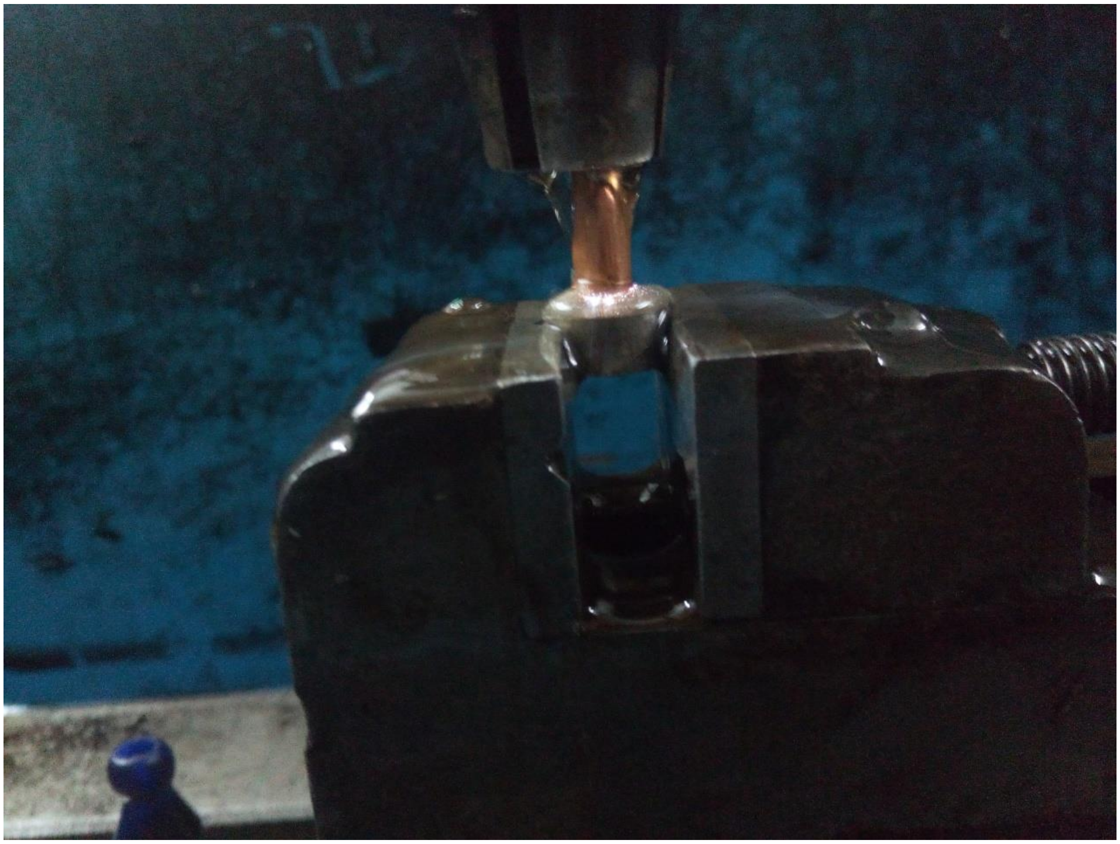

**Figure 4.2 Sparking during low level of EDM parameters**


**Figure 4.3 Control Panel of EDM Machine**

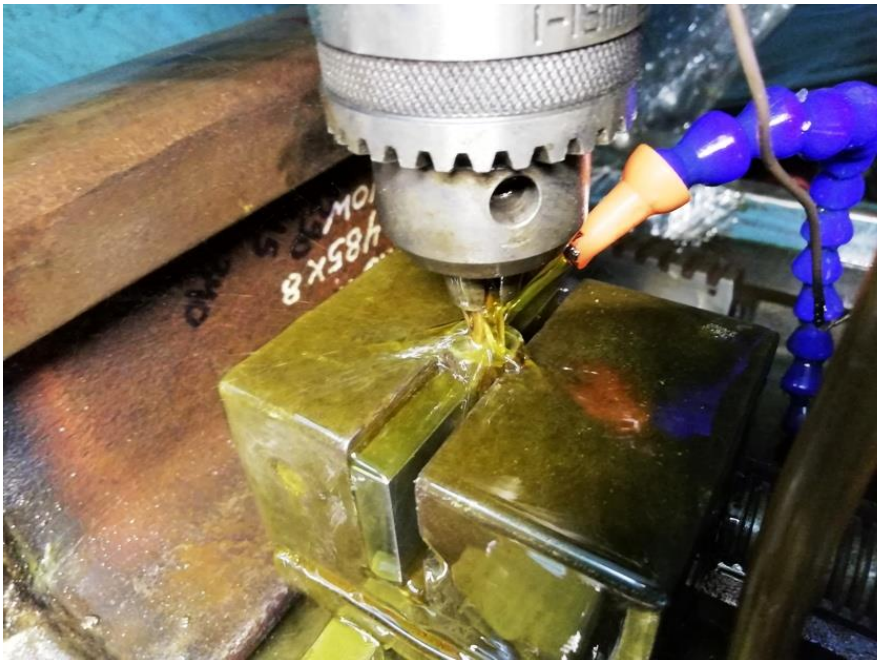

**Figure 4.4 Sparking during EDM machining**

### 4.2 Dielectric Fluid

The dielectric fluid is just like a catalyst conductor, a coolant and is also a flushing medium. The requirements of dielectric fluid are:

1. It should have necessary and constant dielectric strength so as to serve insulation between the tools and work till the breakdown voltage is reached.

2. It must have ability of de-ionizing quickly afterwards the spark ejection takes place.

3. It must have little viscosity with a decent moistening ability so as to provide effective cooling mechanism and removing the swarf particles from the machining gap.

4. It should have ability to flush out the particle produced during the spark out of the gap. This is the most important function of the dielectric fluid. Inadequate flushing will result in arcing which will decrease the life of the electrode and increase the machining time.

5. It should be chemically neutral so that it do not attack the tool, the job, the movable table or the tank.

6. It should have high flash point sothat there are no fire threats.

7. It should not release any toxic vapors.

8. It should maintain its properties with temperature variation, contamination by working residuals and products of decomposition.

9. It should be economical and easily available.

**4.3 Work Piece Material**

The material used for this work is AISI 4140 or EN-19. The samples for experiment were 8 mm thick and 16 mm in diameter which were prepared by a centre lathe. AISI 4140 steel grade is a versatile steel grade. AISI 4140 material is widely used in lot of industrial fields. It is a chromium-molybdenum alloy steel. The chromium content provides good hardness penetration, and the molybdenum content ensures uniform hardness and high strength. AISI 4140 chrome-molybdenum steel can be oil hardened to a relatively high level of hardness. The desirable properties of the AISI steel 4140 include superior toughness, good ductility and good wear resistance in the quenched and tempered condition.

AISI 4140 is used in following components:

1. Shaft
2. Crankshaft
3. Bolt
4. Machinery Parts
5. Gears
6. Milling Spindle
7. Nuts
8. Slides
9. Steel Collet
10. Steel Conveyor or Roller
11. Steel Coupling
12. Drill Collar
13. Steel Ejectors
14. Steel Piston Rods
15. Steel Stub

**Table 4.2: Chemical composition of Work-piece AISI 4140 (EN-19) by weight**

| Material | Fe | S | P | Mn | Cr | C | Si | Mo |
|---|---|---|---|---|---|---|---|---|
| % Composition | 97.295 | 0.04 | 0.035 | 0.85 | 0.95 | 0.40 | 0.23 | 0.20 |

**Table 4.3: Properties of AISI 4140 (EN-19)**

| Density ($g/cm^3$) | Melting point (ºC) | Yeild strength (MPa) | Tensile Strength (MPa) | Elastic modulus (GPa) | Possion's Ratio | Brinell Hardness |
|---|---|---|---|---|---|---|
| 7.85 | 1416 | 415 | 655 | 210 | 0.3 | 197 |

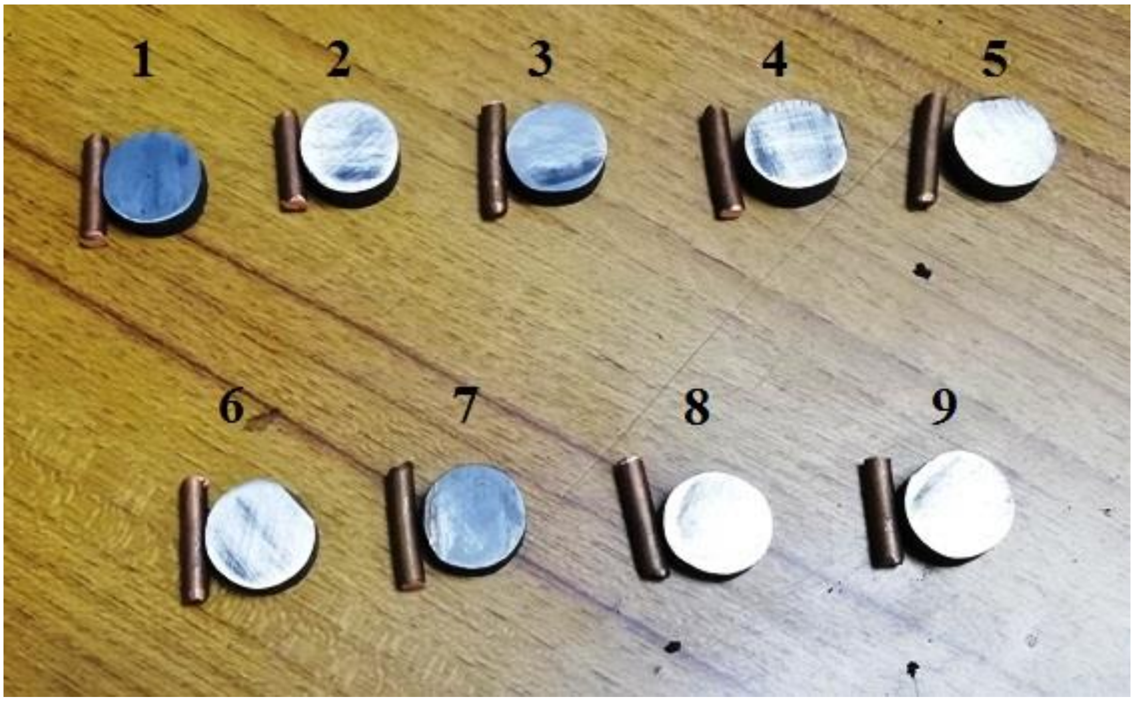


**Figure 4.5: EN-19 un-machined work pieces with copper tools**

### 4.4 Tool Material

The tool or electrode material used for this work is 100% Copper. The tool specimen was prepared of dimensions as 1 inches length and 5 mm diameter. The density of pure copper used as tool is 8.96 $g/cm^3$.

**Figure 4.6: A single Copper Tool**

### 4.5 Material Removal Rate

The rate at which the material removal takes place from the work piece is known as material removal rate. Some metal is melted and then evaporated according to process parameters of electrical discharge machine during machining. The material removal rate is calculated by dividing the loss of weight work piece during machining (in grams) to the product of density of the work piece in gm/cc and the machining time in minutes. Higher is the material removal rate, more is the productivity. Therefore it is most desirable to have larger material removal rate. The formula used to calculate material removal rate is as shown under.

$$\mathbf{MRR} = \frac{\textbf{(Work piece weight loss (gm)) X 1000}}{\textbf{Density (gm/cc) X Machining Time}}$$

### 4.6 Tool Wear Rate

The rate of tool wear from the tool used to machine the work piece during machining is known as tool wear rate. Some material is melted and then evaporated according to process parameters of electrical discharge machine during machining. The tool wear rate is calculated by dividing the loss of tool weight in grams to the product of density of the tool material in gm/cc and the machining time in minutes. It is most desirable to have low tool wear rate. The formula used to calculate tool wear rate is as shown under.

$$\mathbf{TWR} = \frac{\textbf{(Tool weight loss (gm)) X 1000}}{\textbf{Density (gm/cc) X Machining Time}}$$

### 4.7 Weight Measurement

The weight of all specimens is calculated by MH-Series Pocket scale digital weighing measuring instrument available at Dilawar Engineering Works, Lucknow. Figure 4.7 shows the weight measurement of the tool and workpiece.


**Figure 4.7 Measurement of Workpiece weight on digital weighing instrument**


**Figure 4.8 Tool and workpiece with digital weighing instrument before machining**


**Figure 4.9 Specifications of Digital Weight Measuring Instrument**

### 4.8 Radial Overcut

Radial Overcut is measured by CARL ZIESS EVO 50 SEM machine which is available at Department of Material Science and Engineering, IIT Kanpur. Hole size can be analyzed by the linear measurement tool of the machine. It is a non-destructive analysis in which the elements and their concentration in the sample can be determined reasonably accurately.

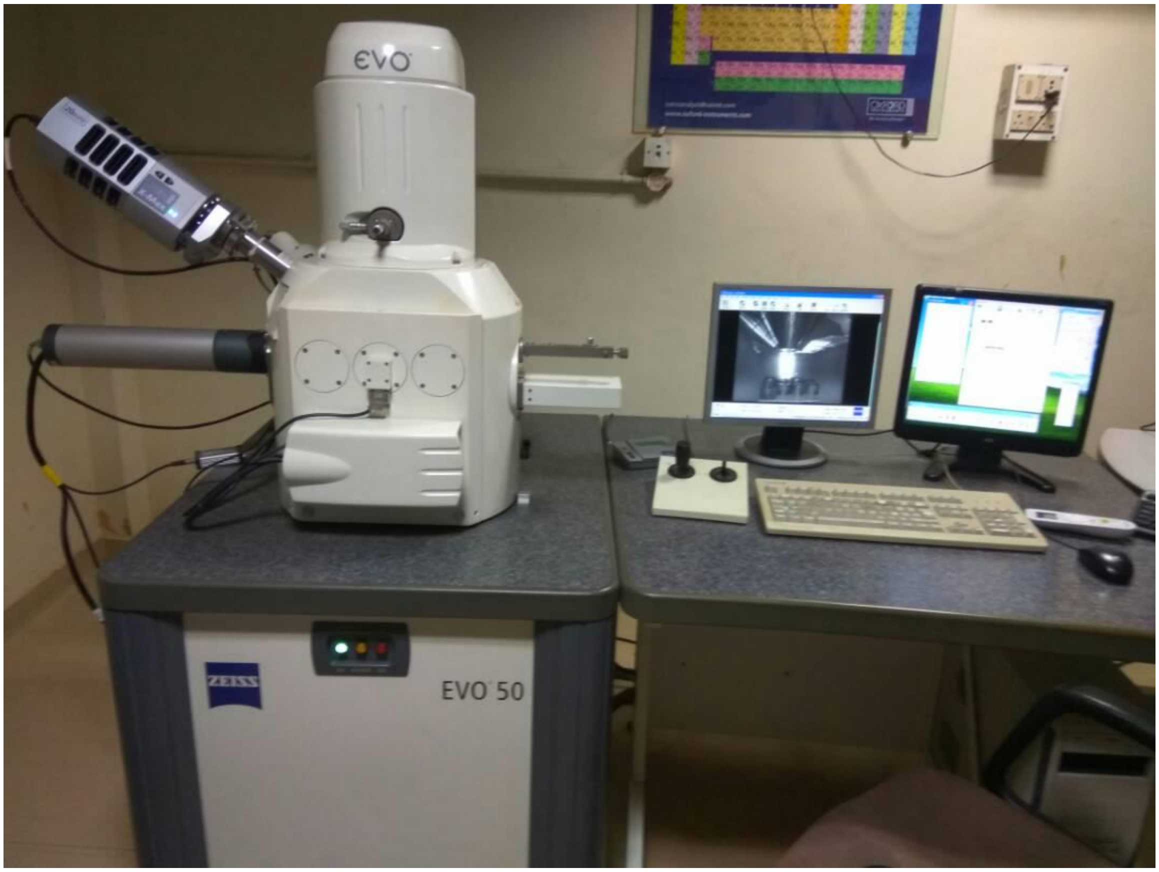


**Figure 4.10 CARL ZEISS EVO 50 SEM MACHINE**
**(COURTESY: DEPT. OF MATERIAL SCIENCE AND ENGINEERING IIT, KANPUR)**

| | |
|---|---|
| Resolution | 2.0nm@ 30kV |
| Acceleration Voltage | 0.2 to 30 kV |
| Magnification | 5x to 1,000,000x |
| Field of View | 8.5 mm at the Analytical Working Distance (AWD) |
| X-ray Analysis | 8.5 mm AWD and 35° take-off angle |
| Detectors | SE in HV - Everhart-Thornley<br>BSD in all modes - quadrant semiconductor diode |

**SPECIFICATION OF CARL ZIESS EVO 50 SEM MACHINE**

# 5

# RESULT AND DISCUSSION

## 5.1 Calculation for MRR

$$\text{MRR} = \frac{\text{(Work piece weight loss (gm)) X 1000}}{\text{Density (gm/cc) X Machining Time}}$$

**Table 5.1: Calculation for MRR of AISI 4140 (EN-19)**

| **Exp. No** | Ip | Ton | Depth of Machining (mm) | **M/c Time** | **MRR($mm^3$/min)** |
|---|---|---|---|---|---|
| **1** | 3 | 20 | 0.5 | 4.56 | 0.559 |
| **2** | 3 | 30 | 0.8 | 12.77 | 0.499 |
| **3** | 3 | 40 | 1.1 | 11.32 | 0.900 |
| **4** | 6 | 20 | 0.8 | 5.35 | 1.429 |
| **5** | 6 | 30 | 1.1 | 6.1 | 1.253 |
| **6** | 6 | 40 | 0.5 | 2.23 | 0.571 |
| **7** | 9 | 20 | 1.1 | 6.13 | 1.039 |
| **8** | 9 | 30 | 0.5 | 2.2 | 1.737 |
| **9** | 9 | 40 | 0.8 | 3 | 2.548 |

For calculation of MRR, the specimen is weighed before machining and after each run using electronic balance. The weight difference gives the amount of material lost during machining which is noted down as weight loss. During machining of specimen, the machining time is also noted down for each run to calculate MRR.

Material removal rate is a performance measure that gives the productivity of EDM process. Material removal rate is calculated by dividing the work piece weight loss in grams to the product of density of the work piece in gm/cc and the machining time in minutes. Using the relation we can get the values of MRR which is shown in Table 5.1

### 5.1.1 Calculation of S/N ratio for MRR

The S/N ratio, which condenses the multiple data points within a trial space, depends on the type of performance measure being evaluated. For calculation of S/N ratio for material removal rate LARGER IS BETTER condition is considered. The equation for the calculation of S/N ratio for material removal rate is:

$$S/N_{LB} = -10 \log \left( \Sigma \left(1/y_i^{2}\right) \right)$$

**Table 5.2 Calculation of S/N ratio for MRR**

| S.No | MRR(mm³/min) | Signal to noise ratio (db) |
|---|---|---|
| **1** | 0.559 | -5.0518 |
| **2** | 0.499 | -6.038 |
| **3** | 0.900 | -0.9152 |
| **4** | 1.429 | 3.10064 |
| **5** | 1.253 | 1.95902 |
| **6** | 0.571 | -4.8673 |
| **7** | 1.039 | 0.33231 |
| **8** | 1.737 | 4.796 |
| **9** | 2.548 | 8.12399 |

### 5.1.2 Calculation of Mean S/N ratio for MRR

Mean S/N ratio is calculated by using following formula

$$nf_i = (nf_1 + nf_2 + nf_3)/3$$

Where nf is mean S/N ratio for factor f at the level value i of the selected factor.

$nf_1$, $nf_2$, $nf_3$ are S/N ratio for factor f at level u

The factors which affect the machining parameters are shown in the table with their respective ranks. Rank of the parameters depends on the delta value. If the delta value of one parameter is more than the other that indicates first rank. Higher value of S/N ratio of each factor shows the optimal level of the factor. For present set of experiment, peak current shows the main influence in the below response table. Pulse on time and depth of machining are observed as less effective as compared to peak current.

**Table 5.3 Calculation of mean S/N ratio for MRR**

| Level | Ip | Ton | Depth of Machining |
|---|---|---|---|
| **1** | -4.00163 | -0.53960 | -1.70768 |
| **2** | 0.06413 | 0.23901 | 1.72888 |
| **3** | 4.41743 | 0.78052 | 0.45873 |
| **Delta** | 8.41907 | 1.32012 | 3.43656 |
| **Rank** | **1** | **3** | **2** |

**Delta = ( Highest mean S/N Ratio – Lowest mean S/N Ratio )**

### 5.1.3 Analysis of Variance for MRR

The following table shows ANOVA of MRR conducted on MINITAB 16.0. The result shows that the contribution of current is most and is 53.88%.

**Table 5.4 ANOVA of MRR**

| Source | DOF | SS | Adj MS | F Value | Contribution |
|---|---|---|---|---|---|
| **Ip** | 2 | 1.9218 | 0.9609 | 1.93 | 53.88% |
| **Ton** | 2 | 0.1643 | 0.0821 | 0.16 | 4.61% |
| **Depth of Machining** | 2 | 0.4826 | 0.2413 | 0.48 | 13.53% |
| **Error** | 2 | 0.9981 | 0.4991 | | 27.98% |
| **Total** | 8 | 3.5668 | | | 100% |

**At least 95% confidence**

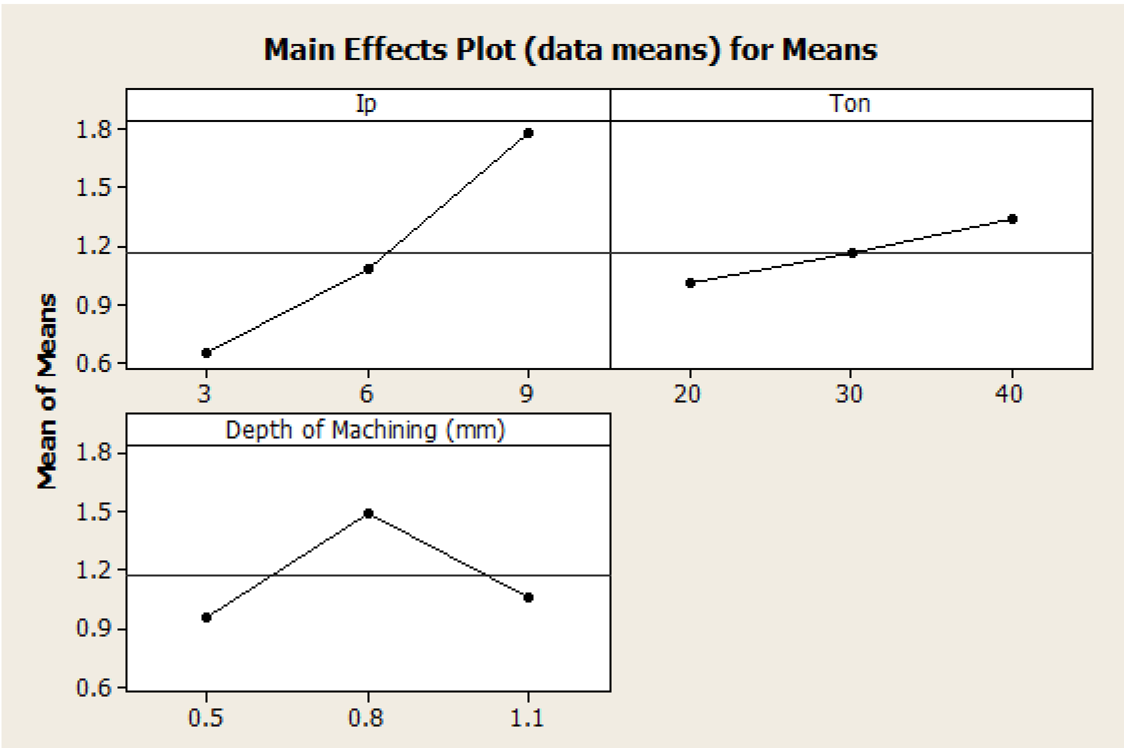


**Figure 5.1: Main effect plot for MRR**

Figure 5.1 presents the mean effect plot for MRR. It shows that the MRR increases with both peak current and pulse on time. In addition, peak current has major influence on MRR. It probably occurred because the intensity of spark is more at higher level of parameter and hence MRR increases. A similar influence is seen when pulse on time is increased.

MRR is observed to follow an initial increasing and then decreasing trend with depth of machining and it is the second most influencing parameter for MRR and has only 13.53% contribution.

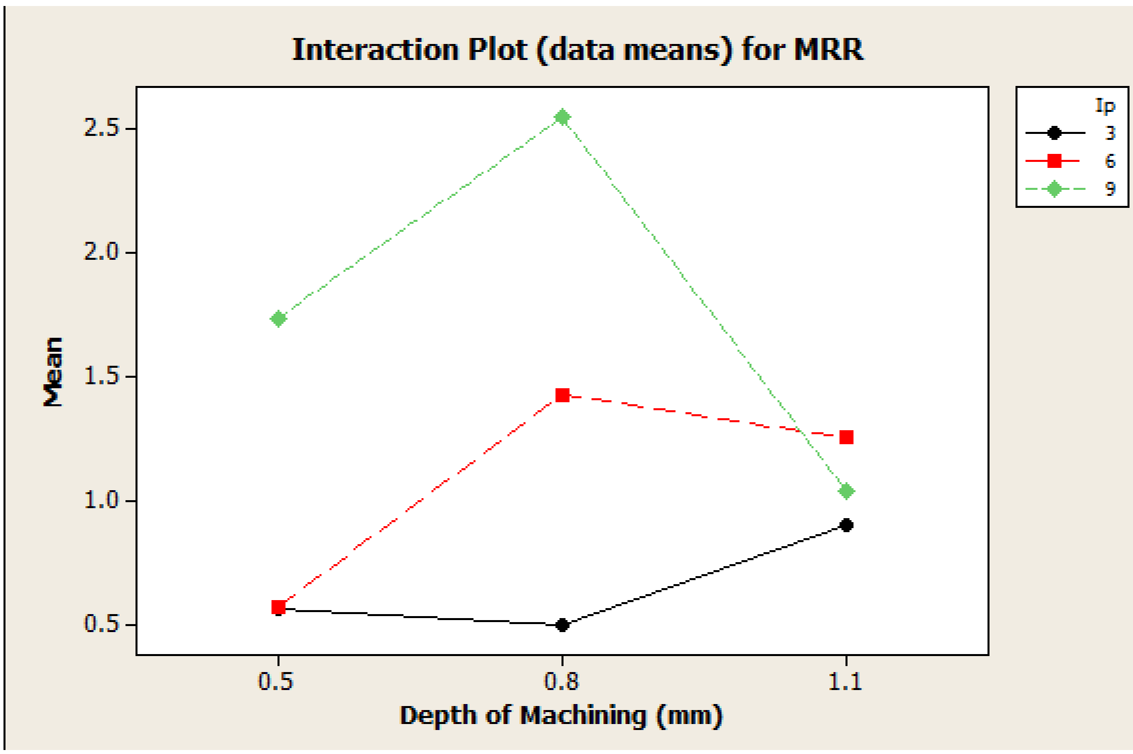


**Figure 5.2: Interaction plot for parameters and MRR**

Figure 5.2 depicts the interaction plot between MRR and depth of machining at different levels of peak current. The plot elucidates that the material removal rate is minimum at lower level of depth of machining. At higher level of peak current, the MRR initially increases with depth of machining. But with further increase in depth of machining, the MRR tends to get reduced.

**Optimal Levels of Parameters for MRR**

- **Peak Current : 9A**
- **Pulse on Time : 40µsec**
- **Depth of Machining : 0.8 mm**

## 5.2 Calculation for Tool Wear Rate

For calculation of TWR, the tool is weighed before machining and after each run using electronic balance. The weight difference gives the amount of material eroded during machining, also the machining time is noted down for each experiment to calculate TWR.

Tool wear rate is calculated by dividing the tool weight loss in grams to the product of density of the tool in gm/cc and the machining time. Using the relation we can get the values of TWR which is shown in Table 5.6

$$\textbf{TWR} = \frac{\textbf{(tool weight loss (gm)) X 1000}}{\textbf{Density (gm/cc) X Machining Time}}$$

**Table 5.5: Calculation for Tool Wear Rate**

| Exp. No | Ip | Ton | Depth of Machining | TWR(mm³/min) |
|---|---|---|---|---|
| **1** | 3 | 20 | 0.5 | 0.245 |
| **2** | 3 | 30 | 0.8 | 0.087 |
| **3** | 3 | 40 | 1.1 | 0.296 |
| **4** | 6 | 20 | 0.8 | 0.626 |
| **5** | 6 | 30 | 1.1 | 0.549 |
| **6** | 6 | 40 | 0.5 | 0.500 |
| **7** | 9 | 20 | 1.1 | 0.364 |
| **8** | 9 | 30 | 0.5 | 0.507 |
| **9** | 9 | 40 | 0.8 | 0.372 |

### 5.2.1 Calculation of S/N ratio for TWR

The S/N ratio, which condenses the multiple data points within a trial, depends on the type of characteristics being evaluated. For calculation of S/N ratio for TWR SMALLER IS BETTER condition is considered. This is considered as the defect and thus it should as low as possible.

The equation for the calculation of S/N ratio for TWR is:

$$S/N_{SB} = -10 \log \left( (1/n) \Sigma y_i^2 \right)$$

**Table 5.6 Calculation of S/N ratio for TWR**

| S.No | TWR($mm^3$/min) | Signal to noise ratio (db) |
|---|---|---|
| **1** | 0.245 | 12.2167 |
| **2** | 0.087 | 21.2096 |
| **3** | 0.296 | 10.5742 |
| **4** | 0.626 | 4.0685 |
| **5** | 0.549 | 5.2086 |
| **6** | 0.500 | 6.0206 |
| **7** | 0.364 | 8.778 |
| **8** | 0.507 | 5.8998 |
| **9** | 0.372 | 8.5891 |

### 5.2.2 Calculation of Mean S/N ratio for TWR

Mean S/N ratio is calculated by using following formula

$$nf_i = (nf_1 + nf_2 + nf_3)/3$$

Where nf is mean S/N ratio for factor f at the level value i of the selected factor.

**Table 5.7 Calculation of mean S/N ratio for TWR**

| Level | Ip | Ton | Toff |
|---|---|---|---|
| **1** | 14.667 | 8.354 | 8.046 |
| **2** | 5.099 | 10.773 | 11.289 |
| **3** | 7.756 | 8.395 | 8.187 |
| **Delta** | 9.568 | 2.418 | 3.243 |
| **Rank** | **1** | **3** | **2** |

### 5.2.3 Analysis of Variance for TWR

The following table 5.9 depicts analysis of variance of tool wear rate during machining of EN-19. The results elucidate that peak current is the most crucial factor for TWR has contributes 80.49% towards TWR. It is also seen that pulse on time is the least influencing parameter and has negligible contribution towards TWR.

**Table 5.8 ANOVA of TWR**

| Source | DOF | SS | Adj MS | F Value | Contribution |
|---|---|---|---|---|---|
| **Ip** | 2 | 0.18456 | 0.09228 | 4.83 | 80.49% |
| **Ton** | 2 | 0.00151 | 0.00075 | 0.04 | 0.66% |
| **Depth of Machining** | 2 | 0.00501 | 0.00251 | 0.13 | 2.18% |
| **Error** | 2 | 0.03821 | 0.01910 | | 16.67% |
| **Total** | 8 | 0.22929 | | | 100% |

**At least 95% confidence**

**Optimal Levels of Parameters for TWR**

- **Peak Current : 3A**
- **Pulse on Time : 30µsec**
- **Depth of Machining : 0.8mm**

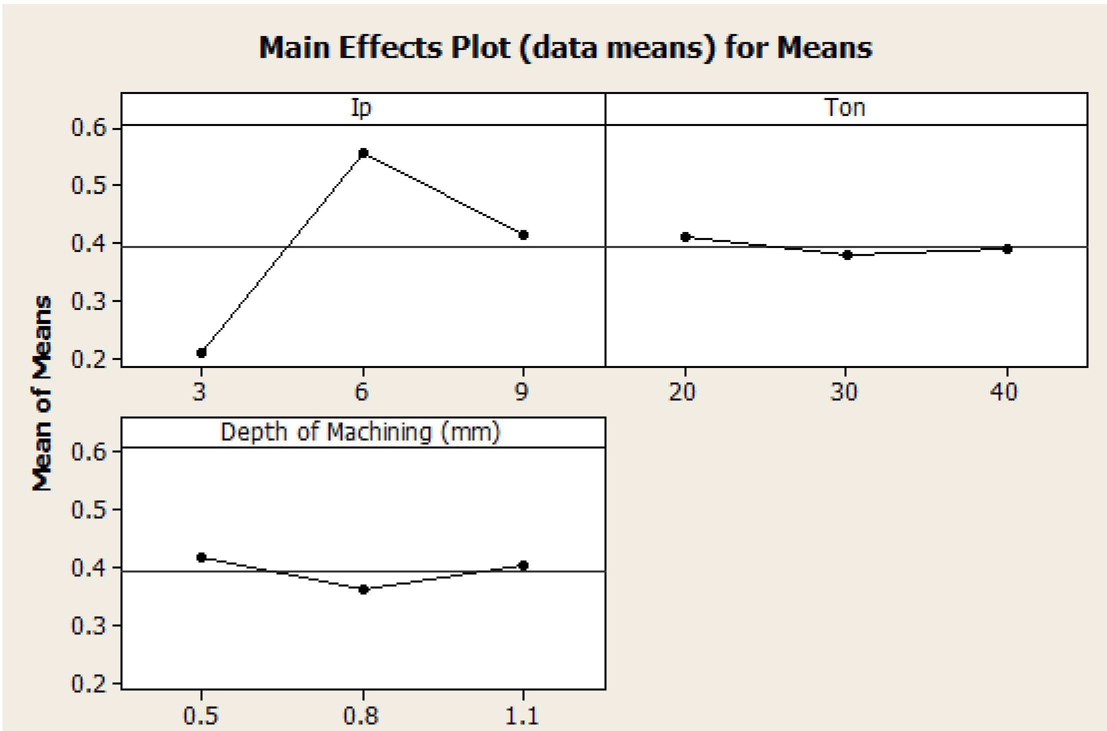


**Figure 5.3: Main effect plot for TWR**

The figure 5.3 illustrates that the tool starts to degrade with increase in levels of peak current but when the value of peak current is increased above 6A, the TWR tends to decrease. This is due to the formation of debris in the spark gap causing the ineffectiveness of the spark intensity. Pulse on time and depth of machining has negligible influence on TWR and the graph obtained are almost flat.

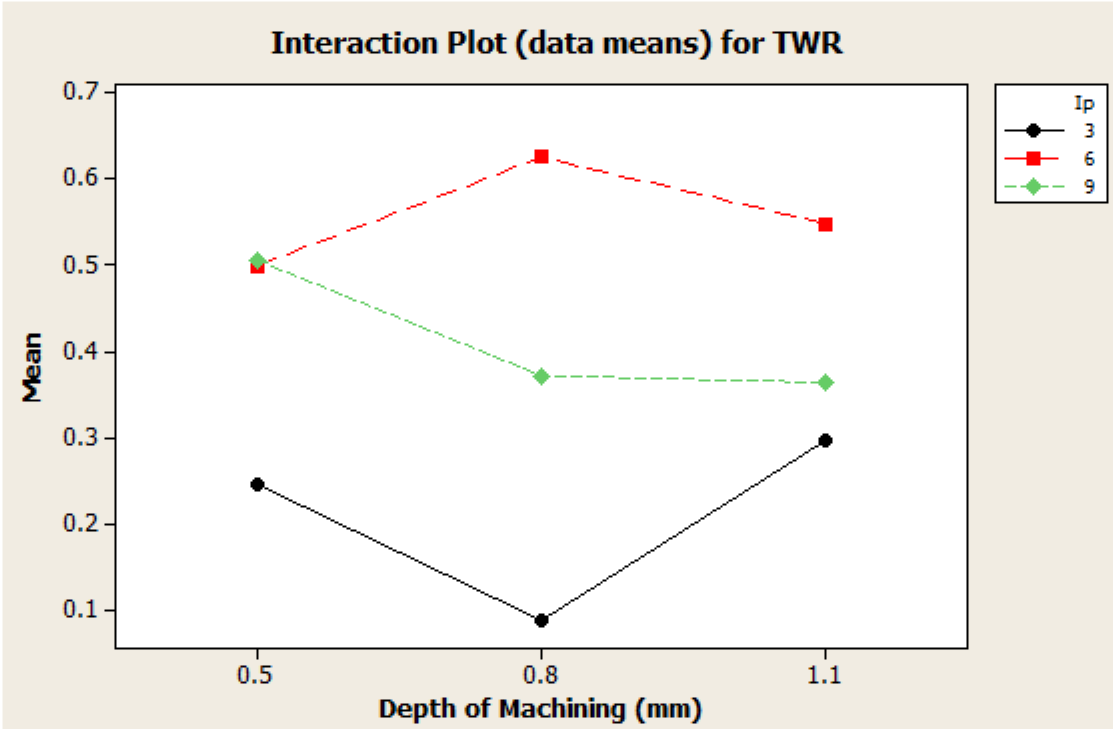


**Figure 5.4: Interaction plot for parameters and TWR**

Figure 5.4 depicts the interaction plot between TWR and depth of machining at different levels of peak current. The plot elucidates that the tool wear rate is initially decreases and then increases with depth of machining at lower level of peak current. When the value of peak current is increased, there is slight decrease in TWR with depth of machining.

### 5.3 Calculation for Radial Overcut

The Radial Overcut in EDM is a defect of machining caused by sparks striking the circumference of the machined hole. These sparks will increase the diameter of the machined hole as compared to diameter of the tool.

Table 5.9 shows the calculation of Radial Overcut varying with current, pulse on time and pulse duty factor.

**Table 5.9: Calculation for Average Radial Overcut**

| Exp. No | Ip | Ton | Depth of Machining (mm) | Radial Overcut (mm) |
|---|---|---|---|---|
| **1** | 3 | 20 | 0.5 | 0.01 |
| **2** | 3 | 30 | 0.8 | 0.02 |
| **3** | 3 | 40 | 1.1 | 0.04 |
| **4** | 6 | 20 | 0.8 | 0.03 |
| **5** | 6 | 30 | 1.1 | 0.05 |
| **6** | 6 | 40 | 0.5 | 0.04 |
| **7** | 9 | 20 | 1.1 | 0.06 |
| **8** | 9 | 30 | 0.5 | 0.02 |
| **9** | 9 | 40 | 0.8 | 0.04 |

### 5.3.1 Calculation of S/N ratio for Radial Overcut

The S/N ratio, which condenses the multiple data points within a trial, depends on the type of characteristics being evaluated. For calculation of S/N ratio for Radial Overcut SMALLER IS BETTER condition is opted. Smaller the Radial Overcut, better is the tolerance achieved. The equation for the calculation of S/N ratio for Radial Overcut is:

$$S/N_{SB} = -10 \log \left( (1/n) \Sigma y_i^2 \right)$$

**Table 5.10 Calculation of S/N ratio for Radial Overcut**

| S.No | Radial Overcut (mm) | Signal to noise ratio (db) |
|---|---|---|
| **1** | 0.01 | 40.000 |
| **2** | 0.02 | 33.979 |
| **3** | 0.04 | 27.959 |
| **4** | 0.03 | 30.458 |
| **5** | 0.05 | 26.021 |
| **6** | 0.04 | 27.959 |
| **7** | 0.06 | 24.437 |
| **8** | 0.02 | 33.979 |
| **9** | 0.04 | 27.959 |

### 5.3.2 Calculation of Mean S/N ratio for Radial Overcut

Mean S/N ratio is calculated by using following formula

$$nf_i = (nf_1 + nf_2 + nf_3)/3$$

Where nf is mean S/N ratio for factor f at the level value i of the selected factor.

$nf_1$, $nf_2$, $nf_3$ are S/N ratio for factor f at level u

**Table 5.11 Calculation of mean S/N ratio for Radial Overcut**

| Level | Current | Pulse on time | Depth of Machining |
|---|---|---|---|
| **1** | 33.98 | 31.63 | 33.98 |
| **2** | 28.15 | 31.33 | 30.80 |
| **3** | 28.79 | 27.96 | 26.14 |
| **Delta** | 5.83 | 3.67 | 7.84 |
| **Rank** | **2** | **3** | **1** |

### 5.3.3 Analysis of Variance for Radial Overcut

ANOVA for Radial Overcut is given in the following table-

**Table 5.12 ANOVA of Radial Overcut**

| Source | DOF | SS | Adj MS | F Value | Contribution |
|---|---|---|---|---|---|
| **Current** | 2 | 0.0005556 | 0.0002778 | 3.57 | 27.48% |
| **Pulse on Time** | 2 | 0.0001556 | 0.0000778 | 1.00 | 7.69% |
| **Depth of Machining** | 2 | 0.0011556 | 0.0005778 | 7.43 | 57.14% |
| **Error** | 2 | 0.0001556 | 0.0000778 | | 7.69% |
| **Total** | 8 | 0.0020222 | | | 100% |

**At least 95% confidence**

**Optimal Levels of Parameters for Radial Overcut**

- **Peak Current : 3A**
- **Pulse on Time : 30µsec**
- **Depth of Machining : 0.5mm**

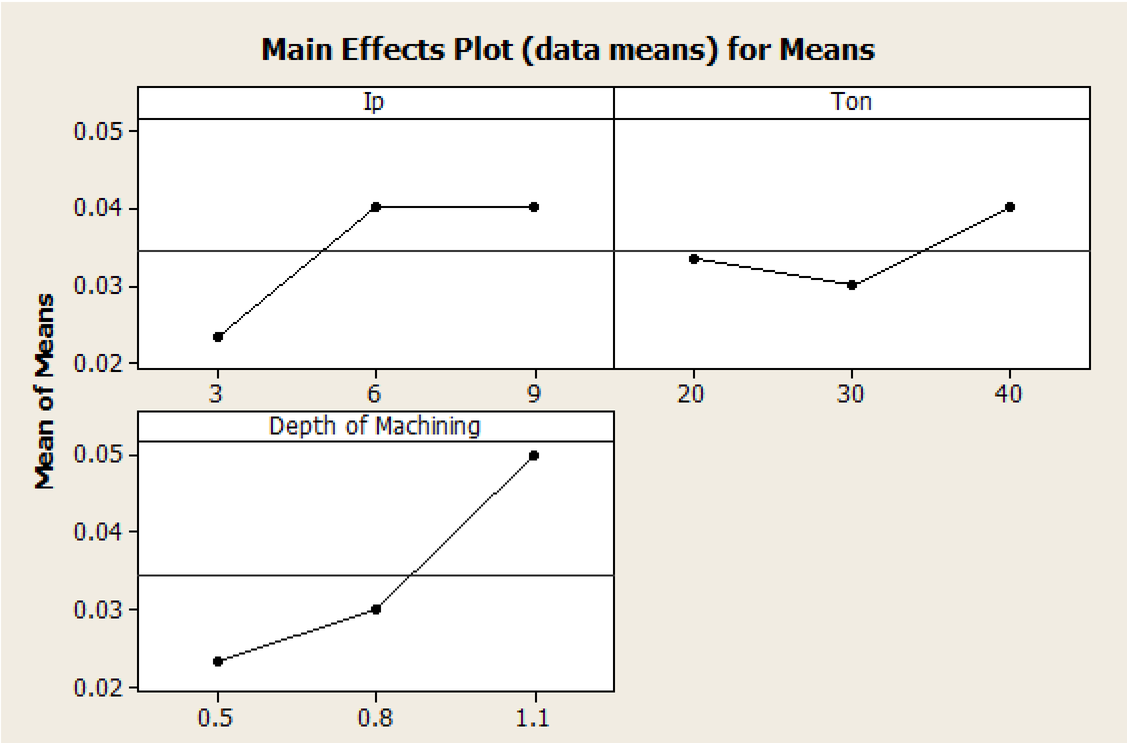


**Figure 5.5 Main effect plot for Radial Overcut**

The above graph shows the effect of input parameters on radial overcut. By increasing the peak current and depth of machining, the radial overcut increases. Depth of machining is the most dominating factor for radial overcut with a contribution of 57.14% and has major influence on it. More number of sparks strike at higher depth of machining, hence influence of depth of machining is highest and radial overcut increases due to more sparks striking the walls of the hole. Peak current is found to be the second most dominating parameter for radial overcut with a contribution of 27.48%. With pulse on time, the radial overcut first decreases. On further increase in pulse on time value, the radial overcut tends to increase. Pulse on time has least influence on radial overcut and has a contribution of only 7.69%.

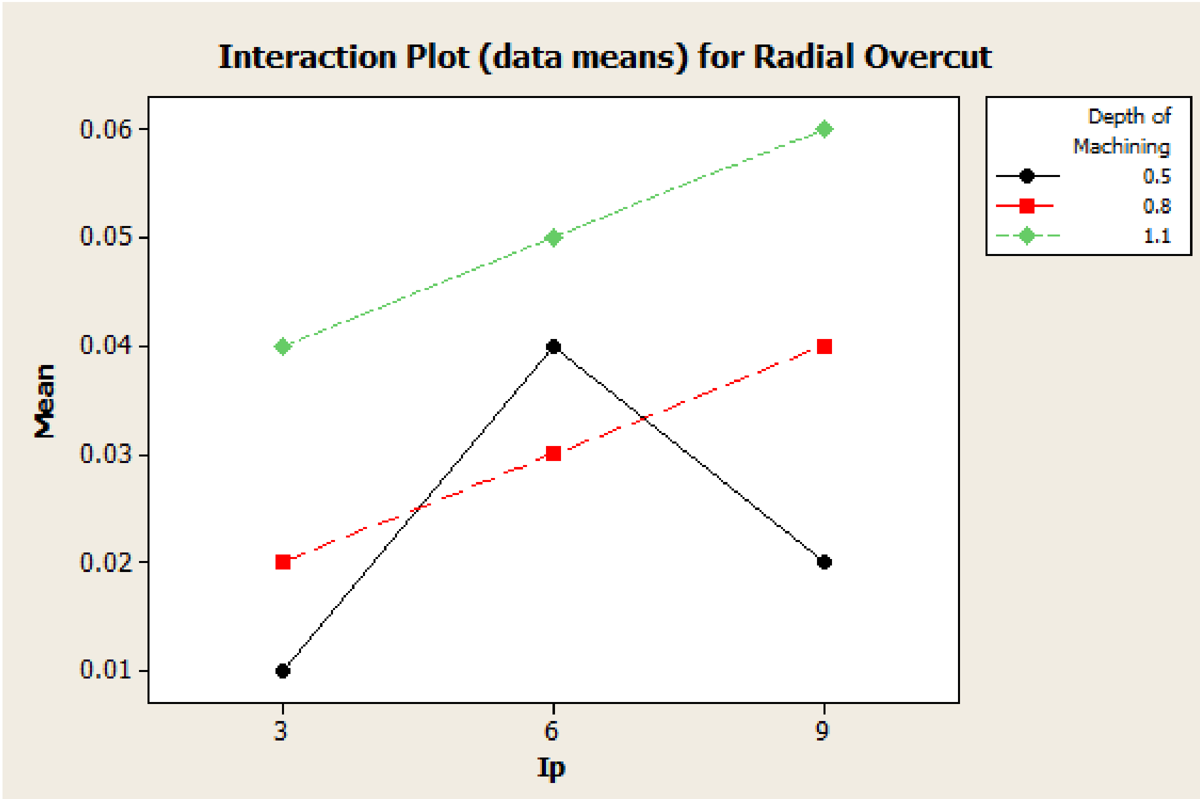


**Figure 5.6: Interaction plot for parameters and Radial Overcut**

Figure 5.6 depicts the interaction plot between Radial overcut and peak current at different levels of depth of machining. The plot elucidates that the radial overcut is influenced by peak current at each level of depth of machining. At lower level of depth of machining, the radial overcut initially increases and then tends to decrease with peak current. When the value of depth of machining is increased, there is much increase in radial overcut with peak current and an increasing trend is observed.

## SEM FIGURES OF RADIAL OVERCUT

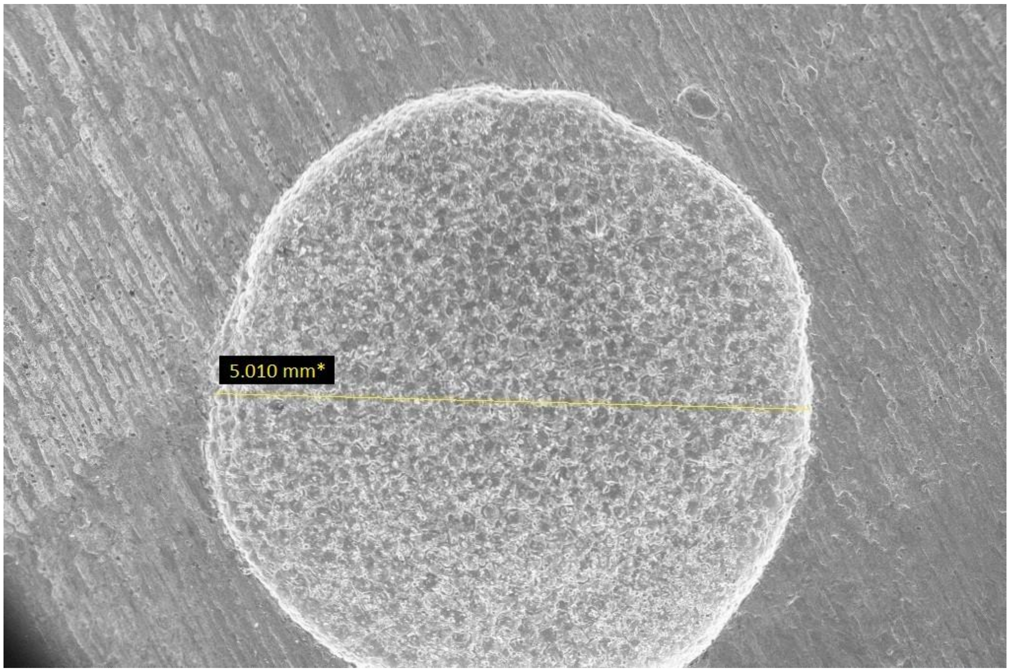


**Figure 5.7: SEM of Sample 1**

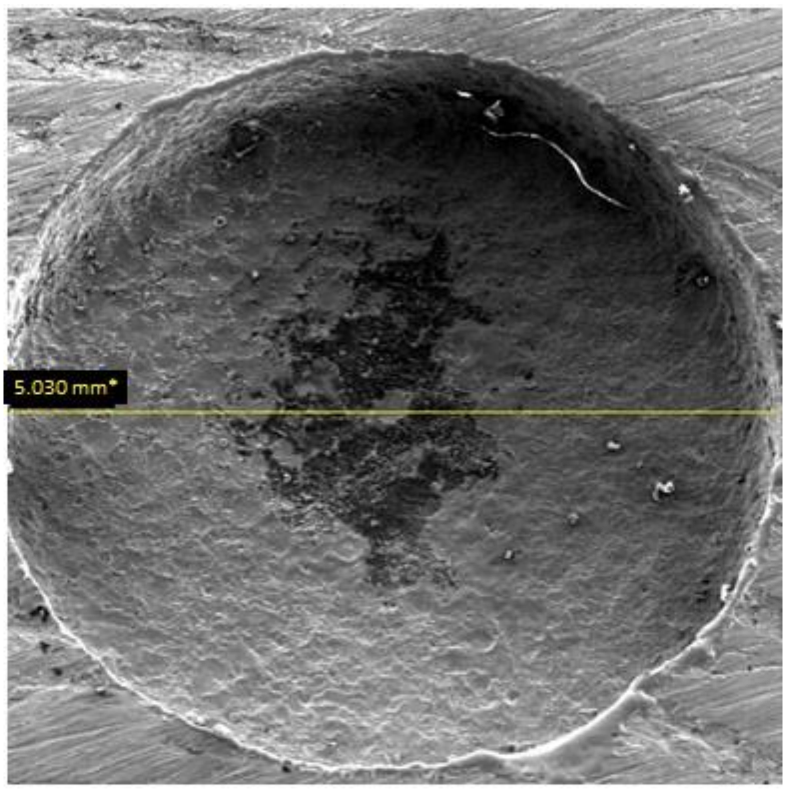


**Figure 5.8: SEM of Sample 4**

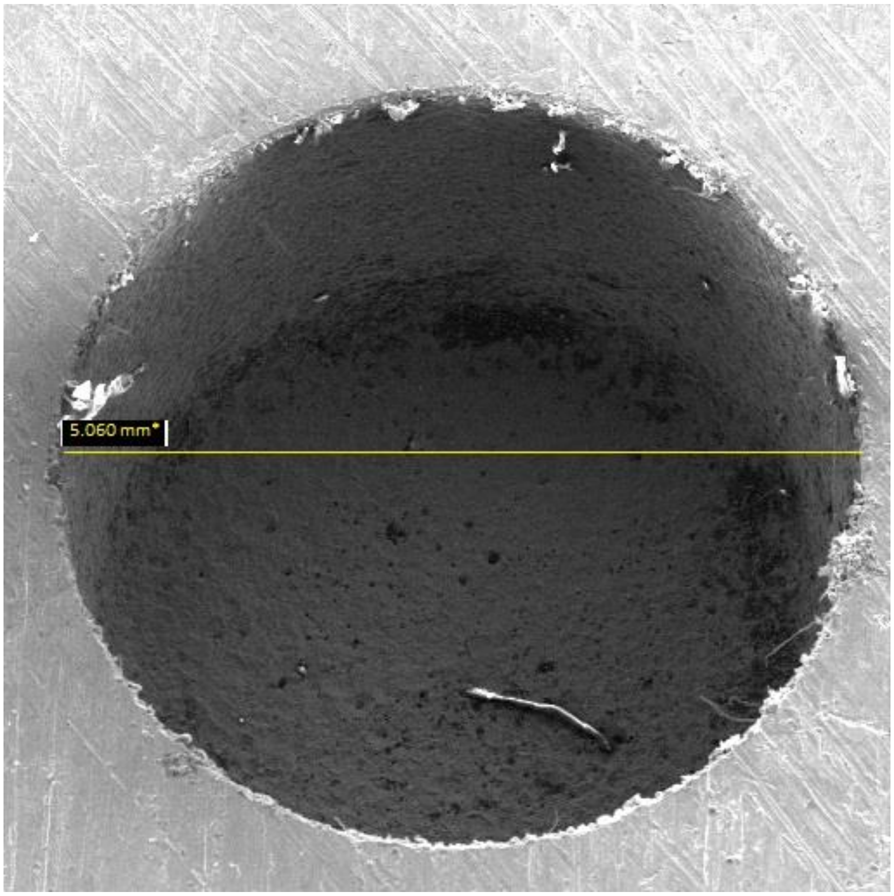


**Figure 5.9: SEM of Sample 7**

### 5.4 Confirmation Test

Confirmation tests have been performed for MRR, TWR and Radial Overcut with their optimum levels of process variables.

**Table 5.14: Confirmation of expected and actual values of MRR**

| Experiment No. | Optimum Machining Parameters | | | MRR (gm/min) | |
|---|---|---|---|---|---|
| | Current (A) | Pulse on Time (μsec) | Depth of Machining (mm) | Actual | Expected |
| 1 | 9 | 40 | 0.8 | 2.548 | 2.431 |
| | | | | Error (%) | 4.59% |

**Table 5.15: Confirmation of expected and actual values of TWR**

| Experiment No. | Optimum Machining Parameters | | | TWR | |
|---|---|---|---|---|---|
| | Current (A) | Pulse on Time (µsec) | Depth of Machining (mm) | Actual | Expected |
| 1 | 3 | 30 | 0.8 | 0.087 | 0.085 |
| | | | | Error (%) | 2.30% |

**Table 5.16: Confirmation of expected and actual values of Radial Overcut**

| Experiment No. | Optimum Machining Parameters | | | Radial Overcut | |
|---|---|---|---|---|---|
| | Current (A) | Pulse on Time (µsec) | Depth of Machining (mm) | Actual | Expected |
| 1 | 3 | 30 | 0.5 | 0.01 | 0.01 |
| | | | | Error (%) | 0.00% |

# 6

# CONCLUSIONS

## 6.1 CONCLUSION

The present experimental study describes the optimization of input machining parameters in Electrical Discharge Machining of EN-19 with copper electrode using L9 orthogonal array of Taguchi method. Factors like Current, Pulse on Time and Depth of Machining and their interactions were found. These results show the performance of parameters at different levels to optimize the MRR, TWR and Radial Overcut. Following conclusions are made:

- Material Removal Rate increases with both peak current and pulse on time. In addition, peak current has major influence on MRR. It probably occurred because the intensity of spark is more at higher level of parameter and hence MRR increases. The result shows that the contribution of current is most and is 53.88%. A similar influence is seen when pulse on time is increased.
- Material Removal Rate is observed to follow an initial increasing and then decreasing trend with depth of machining and it is the second most influencing parameter for MRR and has only 13.53% contribution.
- The tool starts to degrade with increase in levels of peak current but when the value of peak current is increased above 6A, the TWR tends to decrease. This is due to the formation of debris in the spark gap causing the ineffectiveness of the spark intensity. Pulse on time and depth of machining has negligible influence on TWR and the graph obtained are almost flat.

- The results also elucidates that peak current is the most crucial factor for TWR has contributes 80.49% towards TWR. It is also seen that pulse on time is the least influencing parameter and has negligible contribution towards TWR.
- By increasing the peak current and depth of machining, the radial overcut increases. Depth of machining is the most dominating factor for radial overcut with a contribution of 57.14% and has major influence on it. More number of sparks strike at higher depth of machining, hence influence of depth of machining is highest and radial overcut increases due to more sparks striking the walls of the hole.
- Peak current is found to be the second most dominating parameter for radial overcut with a contribution of 27.48%. With pulse on time, the radial overcut first decreases. On further increase in pulse on time value, the radial overcut tends to increase. Pulse on time has least influence on radial overcut and has a contribution of only 7.69%.

# 7

# REFERENCES

[1] Subramanian Gopalakannan and Thiagarajan Senthilvelan “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.

[2] Pravin R. Kubade and V. S. Jadhav “An Experimental Investigation of Electrode Wear Rate (EWR), Material Removal Rate (MRR) and Radial Overcut (ROC) in EDM of High Carbon-High Chromium Steel (AISI D3)” International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-1, Issue-5, June 2012.

[3] Shishir Mohan Shrivastava and A.K. Sarathe “Influence of Process Parameters and Electrode Shape Configuration On Material Removal Rate, Surface Roughness And Electrode Wear In Die Sinking EDM: A Review” International Journal of Emerging Technology and Advanced Engineering Volume 4, Issue 4, April 2014.

[4] Abhishek Gaikwad, Amit Tiwari, Amit Kumar and Dhananjay Singh, “Effect of EDM parameters in obtaining maximum MRR and minimum EWR by machining SS 316 using Copper electrode” International Journal of Mechanical Engineering and Technology (IJMET) ISSN 0976.

[5] Y.H. Guu and Max Ti-Quang Hou, “Effect of machining parameters on surface textures in EDM of Fe-Mn-Al alloy” Material Science and Engineering A 466 (2007) 61-67.

[6] PP.M. George, B.K. Rahunath, L.M. Manocha and Ashish M. Warrier, “EDM machining of carbon composite a Taguchi approach”, Journal of Material Processing Technology 145(2004) 66-71.

[7] C.H. Cheron, J.A Ghani, Y.K. Seong and C.Y. Swee, “Copper and graphite electrodes performance in electrode discharge machining of XW42 tool steel” journal of materials processing technology (2008).

[8] Ahmet Hascalık and Ulas Caydas “Electrical discharge machining of Titanium alloy (Ti–6Al–4V)” Applied Surface Science 253 (2007) 9007–9016.

[9] D. K. Ojha, S. Panda, D.Mishra “A Study on Effect of EDM Process Parameters on AISI 304L Stainless Steel”26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th–14th, 2014

[10] M M Sari, M Y Noordin and E Brusa “Evaluating the electrical discharge machining (EDM) parameters with using carbon nanotubes” International Conference on Structural Nano Composites (NANOSTRUC 2012)

[11] Deepu P.Nair, Dr. Binu C.Yeldose, Dr. Cibu K. Varghese, “Investigation of Surface Roughness on M300 Steel Machined By EDM”, International Journal of Engineering and Innovative Technology (IJEIT) Volume 4, Issue 2, August 2014.

[12] S. Ben Salem , W. Tebni , E. Bayraktar, “Prediction of surface roughness by experimental design methodology in Electrical Discharge Machining (EDM)”, Journals of Achievements in Materials and Manufacturing Engineering Volume 49 Issue 2 December 2011.

[13] V. Chandrasekaran, D. Kanagarajan, R. Karthikeyan, “Optimization of EDM Characteristics of WC/5ni Composites Using Response Surface Methodology”, International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-2, Issue-5, November 2013.

[14] Francesco Modica, Valeria Marrocco, Giacomo Copani and Irene Fassi Sustainability 2011, *3*, 2456-2469; Sustainable Micro-Manufacturing of Micro-Components via Micro Electrical Discharge Machining.

[15] Kumar Sandeep, Research Journal of Engineering Sciences Volume 2(2), 56-60, February (2013) “Current Research Trends in Electrical Discharge Machining”.

[16] W.S. Lau, M. Wang and W.B. Lee, “Electric discharge machining of Carbon fiber composite materials” Int. J. Machine Tools Manufacture. Volume 30, No. 2, pp.297-308, 1990.

[17] Amoljit S. Gill, Sanjeev Kumar, “Surface Roughness Evaluation for EDM of En31 with Cu-Cr-Ni Powder Metallurgy Tool”, International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering Vol:8, No:7, 2014.

[18] Navdeep Malhotra, Sona Rani and Khalid Sheikh, “Optimization of control parameters for surface roughness in side flushing form of die sink EDM”, Journal of engineering research and studies 2011228-233.

[19] H.T.Lee and T.Y.Tai, “Relationship between EDM parameters and surface crack formation” Journal of Materials Processing Technology 142 (2003) 676-683.

[20] Rajesha S, C.S. Jawalkar, Radha Raman Mishra, A.K. Sharma, Pradeep Kumar, “Study of Recast Layers and Surface Roughness on Al-7075 metal matrix composite during EDM machining”, International Journal of Recent advances in Mechanical Engineering (IJMECH) Vol.3, No.1, February 2014.

[21] Harpuneet Singh, “Investigating the Effect of Copper Chromium and Aluminum Electrodes on EN-31 Die Steel on Electric Discharge Machine Using Positive Polarity”, Proceedings of the World Congress on Engineering 2012 Vol III WCE 2012, July 4 - 6, 2012, London, U.K.

[22] Gurtej Singh, Paramjit Singh, Gaurav Tejpal, Baljinder Singh, “Effect of machining parameters on H13 STEEL in EDM process using powder mixed fluid”, International Journal of Advanced Engineering Research and Studies, E-ISSN2249–8974.

[23] Khalid Hussain SYED, Kuppan PALANIYANDI, “Performance of electrical discharge machining using aluminiumpowder suspended distilled water”,Turkish J. Eng. Env. Sci. 36 (2012) , 195 – 207.

[24] Banh Tien Long, Ngo Cuong, Nguyen Huu Phan, Pichai Janmanee, “Machining Properties Evaluation of Copper and Graphite Electrodes in PMEDM of SKD61 Steel in Rough Machining”, International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-4 Issue-3, February 2015.

[25]Sushil Kumar Choudhary and Dr. R.S Jadoun , “Current Advanced Research Development of Electric Discharge Machining (EDM): A Review”, International Journal of Research in Advent Technology, Vol.2, No.3, March 2014 E-ISSN: 2321-9637.

[26] PR Dewan, “Latest Trends in Electro Discharge Machining” European Journal of Advances in Engineering and Technology, 2015, 2(5): 66-71 ISSN: 2394 - 658X.

[27] Shaaz Abulais, “Current Research trends in Electric Discharge Machining(EDM): Review” International Journal of Scientific & Engineering Research, Volume 5, Issue 6, June-2014, 100 ISSN 2229-5518.

[28] A.K.M. Asif Iqbal and Ahsan Ali Khan “Influence of Process Parameters on Electrical Discharge Machined Job Surface Integrity” American Journal of Engineering and Applied Sciences 3 (2): 396-402, 2010.

[29] YN. Annamalai, V. Sivaramakrishnan, B. Suresh kumar, N.Baskar, “Investigation and Modeling of ElectricalDischarge Machining Process Parameters for AISI 4340 steel” International Journal of Engineering and Technology (IJET) Vol 5 No 6 Dec 2013-Jan 2014.

# LIST OF PUBLICATIONS

"Investigation of MRR , TWR and Radial Overcut at Varying Depth of Machining during Die Sinking EDM", Gulshan Kumar , Sumita Chaturvedi , Syed Asghar Husain Rizvi, International Journal of Research in Applied Science & Engineering Technology , Volume 8 Issue IX September 2020

ISSN No. : 2321-9653

iJRASET

International Journal for Research in Applied Science & Engineering Technology

IJRASET is indexed with Crossref for DOI-DOI : 10.22214

Website : www.ijraset.com, E-mail : ijraset@gmail.com

ISRA Journal Impact Factor: **7.429**

45.98 INDEX COPERNICUS

THOMSON REUTERS Researcher ID: N-9681-2016

10.22214/IJRASET

TOGETHER WE REACH THE GOAL SJIF 7.429

# Certificate

*It is here by certified that the paper ID : IJRASET31342, entitled*

*Investigation of MRR, TWR and Radial Overcut at Varying Depth of Machining during Die Sinking EDM*

*by*

*Gulshan Kumar*

*after review is found suitable and has been published in*

*Volume 8, Issue IX, September 2020*

*in*

*International Journal for Research in Applied Science & Engineering Technology*

*Good luck for your future endeavors*

Editor in Chief, iJRASET

ISSN No. : 2321-9653

iJRASET

International Journal for Research in Applied Science & Engineering Technology

IJRASET is indexed with Crossref for DOI-DOI : 10.22214

Website : www.ijraset.com, E-mail : ijraset@gmail.com

ISRA Journal Impact Factor: 7.429

45.98 INDEX COPERNICUS

THOMSON REUTERS
Researcher ID: N-9681-2016

10.22214/IJRASET

TOGETHER WE REACH THE GOAL
SJIF 7.429

# Certificate

*It is here by certified that the paper ID : IJRASET31342, entitled*

*Investigation of MRR, TWR and Radial Overcut at Varying Depth of Machining during Die Sinking EDM*

*by*

*Sumita Chaturvedi*

*after review is found suitable and has been published in*

*Volume 8, Issue IX, September 2020*

*in*

*International Journal for Research in Applied Science & Engineering Technology*

*Good luck for your future endeavors*

Editor in Chief, iJRASET

ISSN No. : 2321-9653

# iJRASET

International Journal for Research in Applied Science & Engineering Technology

IJRASET is indexed with Crossref for DOI-DOI : 10.22214

Website : www.ijraset.com, E-mail : ijraset@gmail.com

ISRA Journal Impact Factor: 7.429

45.98 INDEX COPERNICUS

THOMSON REUTERS Researcher ID: N-9681-2016

10.22214/IJRASET

TOGETHER WE REACH THE GOAL SJIF 7.429

## Certificate

*It is here by certified that the paper ID : IJRASET31342, entitled*

*Investigation of MRR, TWR and Radial Overcut at Varying Depth of Machining during Die Sinking EDM*

*by*

*Syed Asghar Husain Rizvi*

*after review is found suitable and has been published in*

*Volume 8, Issue IX, September 2020*

*in*

*International Journal for Research in Applied Science & Engineering Technology*

*Good luck for your future endeavors*

Editor in Chief, iJRASET