"Experimental Investigation on EDM of EN-8 Using Copper Tools"

A Thesis

Submitted

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF TECHNOLOGY

In

Production and Industrial Engineering

Submitted by

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July,2022

CERTIFICATE

This is to secure that this is work eligible "**Experimental Investigation on EDM of EN-8 Using Copper Tools"** submitted by **Mr. Shivardhan Goswami (Enroll.No.1900103783)** in partial fulfillment for grant of Master of Technology in Mechanical Engineering Department with specialization in Mechanical Engineering **(Production and Industrial Engineering)** to **INTEGRAL UNIVERSITY, Lucknow (U.P.)**. He has done his work under my superintendence and direction and superior insight; the issue encapsulated in this proposition has not been present to some other University/Institute for honor of any masters-degree to the hopeful or to any other person.

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the thesis entitled "**Experimental Investigation on EDM of EN-8 Using Copper Tools"**, submitted to the Dept. of Mechanical Engineering, **INTEGRAL UNIVERSITY, Lucknow (U.P.),** India for award of degree of Master of Technology in Mechanical Engineering **(Production and Industrial Engineering),** is an authentic record of my own work carried out during my M.tech course under the supervision of **Dr. Mohd Shadab Khan** .

I have not submitted the matter presented in the thesis for the award of any other degree of this or any other university.

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ACKNOWLEDGEMENT

I might want to emphasize my intense feeling of apprehension and regard to my supervisor **Dr. Mohd Shadab Khan,** Associate Professor, Department of Mechanical Engineering for his significant direction, inspiration and motivation and for his involvement in order to raise this theory in introduce frame. I see myself privileged to have the capacity to work under the direction of such an inducement identity.

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

My special thanks to **Dr. Mohd. Anas**, Associate Professor, Department of Mechanical Engineering for his valuable guidance during this research work.

My special thanks to my wife who is supporting in all the situations for successfully completing my work and all my relatives. I want to thanks my friend Mr. Abhishek and Mr.Pawan for supporting during this research work. Their adoration, friendship and persistence made this work conceivable and favors of my dearest guardians significantly sub serve me doing this research work.

Shivardhan Goswami

ABSTRACT

Electrical discharge machining (EDM) is a powerful, nonconventional machining technique with the ability to machine any conductive material regardless of mechanical property. However, the sluggish nature of EDM stands out when the target is in mass production in industrial plants. Poor surface quality, residual stress, and heat-affected zone are among other disadvantages of this technique. Researchers have proposed several solutions to enhance EDM capabilities by utilizing more innovative materials or methods.

EDM machine is a non-conventional machine which is used to cut alloy materials with high hardness, impact resistance and toughness. It can cut complex contours which are difficult to be machined by conventional cutting methods. The present investigation is conducted on EDM is performed on EN-8 with copper as electrode to establish the relationship between process parameters of EDM on material removal rate, tool wear rate and white layer thickness. The investigation concluded that material removal rate, tool wear rate and white layer thickness were majorly influenced by the peak current and pulse on time. Pulse off time was found to be the least dominating parameter for all the performance measures.

TABLE OF CONTENTS

List of Table

LIST OF FIGURES

1

INTRODUCTION

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.

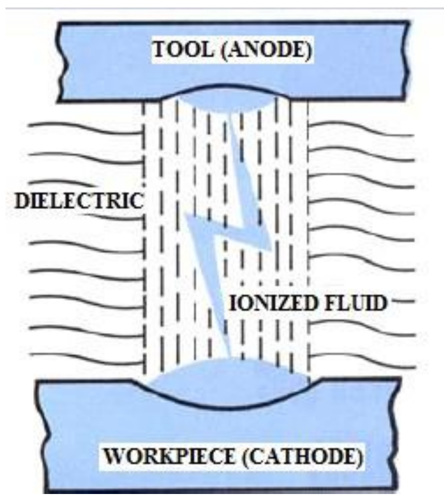


Figure 1.1 Description of EDM process

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 electricallyconductive.

The EDM process is used in two different ways:

1. A pre-shaped electrode or a too), usually graphite or copper, is in shape of a cavity to be producedon 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.

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 maintains a gap of low thickness between the tool and the work, preventing them from contacting eachother. 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 becauseof the overcut or enlargement.

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.

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.

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 theworkpiece, 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.

PARAMETERS OF EDM

The parameters of EDM are mainly classified into following two categories

1) The process parameters

2) The performance parameters

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.

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 increasesbut 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 unstablesparks.

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.

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.

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 lowercosts.

• It is a burr-free process.

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

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.

Applications of EDM

Prototype Production

The EDM process is a most widely used by the mould making process in die 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.

Coinage Dies Making

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

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 1.2 Setup of EDM for the experiments

2

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.

Abhishek Gaikwad [1] conducted an experimental effect of EDM parameters in obtaining max MRR and min TWR by machining SS316 using copper tool and concluded that the parameter toff is the most effective for MRR and current for TWR.

V. Vikram Reddy [2] conducted an experimental Optimization of Process Parameters during EDM of Stainless Steel 304 using Taguchi Method and concluded that Peak current, pulse on time and pulse off time are significant parameters affecting MRR, TWR and SR.

Suraj Choudhary [3] conducted an experimental analysis of MRR and SR with different electrode for SS316 on die sinking EDM using Taguchi Technique and concluded that electrode material parameter is most effective for MRR and SR. Pulse on time is the least influence parameter for MRR and SR.

V. Chandrasekaran [4] through their examination uncovered that the MRR is most astounding for all syntheses. As the level of nickel builds the warm conductivity of the piece increments since the nickel material is effectively expelled from the surface of the parent material. Thus the MRR increases with increment in the level of nickel. It is likewise discovered that the surface harshness increments with current and flushing weight and doesn't rely upon level of Ni. The ideal Ra esteems diminished with expanding anode pivot.

Francesco Modica et. al. [5] 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 [6] investigated surface quality and metal removal rate which are the utmost important factors for selecting the optimum condition of processes and also the economic aspects. The research reported the trend of research in EDM.

Lau et al [7] established the feasibility of using Electrical Discharge Machining for machining carbon fiber composite materials. Parameters selected were currents, pulse durations, tool materials andpolarities 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 [8]** on EN31with Cu-Cr-Ni Powder Metallurgy Tool found that current is the most contributing parameter towards surface roughness. **Navdeep Malhotra et al [9]** 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 [10] 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 [11]** 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.

Pravin R. Kubade et al [12] studied the dominance of EDM parameters on tool wear rate, material removal rate and radial overcut of AISI D3 using a copper electrode. The results revealed that MRR is mainly dominated by peak current while other factors were less effective. Tool wear rate is majorly influenced by both peak current and pulse on time, while duty cycle and gap voltage were very less effective on it. Peak current also has the major influence on radial overcut followed by duty cycle and pulse on time while almost very less influence was observed by gap voltage.

Harpuneet Singh [13] 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 [14] 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 [15] 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.

Kuldeep Ojha et al [16] reviewed for MRR improvement in Electrical Discharge Machining and found that the basis of controlling and improving MRR mostly relies on empirical methods. This is majorly because of the stochastic nature of the sparking phenomenon that involves both electrical and non-electrical process parameters. They also concluded that MRR has been getting overwhelming research potential from the invention of EDM process, and it requires more experimentation in future.

Banh Tien Long et al [17] 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.

Harpuneet Singh [18] studied the effect of Cu-Chromium and Al electrodes on EN-31 using Electric Discharge Machine with positive polarity and they concluded that the depth of cut is better for copper chromium electrodes as compared to brass. It increases with increase in pulsed current in case of brass and remains same for copper chromium. Over cut is better of brass when compared to copper chromium. The best result for over cut is achieved at 12A. Hardness is better for brass as compared with copper Chromium. Copper chromium electrode has low Tool wear as compared to Brass. The MRR is better for copper chromium at all the values of pulsated current except at 6A as compared to Brass.

In an investigation conducted by **George et al [21]** optimized the machining parameters in the EDM machining of C-C composite using Taguchi method. The process parameters influences the tool wear rate and MRR. The relative significance of parameters is gap voltage, peak current and pulse on time respectively. **Sushil Kumar Choudhary et al [22]** 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 [23]** 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 [24]** 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.

C.H. Cheron [25] 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 [26]** 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.

Francesco Modica, Valeria Marrocco, Giacomo Copani and Irene Fassi [27] aimed of investigation to shed a light on the relation and dependence between the material removal process, identified in the calculation of material removal rate and tool wear ratio. The most important parameters considered are open voltage, discharge current, pulse width and frequency, for experimentally quantifying the material waste that is produced and optimize the technological process in order to decrease it.

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. In another study conducted by **Satpal**

Singh and C.S. Kalra [30], an experimental investigation of PMEDM with tungsten powder mixed in dielectric was performed on EN 24 steel concluded that MRR shows an increasing trend with increase in powder concentration. Higher MRR has been obtained in PMEDM as compared to conventional EDM. MRR firstly increases and then decreases with increase in pulse on time.

N. Annamalai et al [31] in their investigation concluded that the effect on MRR improves when peak current and pulse on time are increased whereas there is no much impact when pulse off time is increased. The Electrode Wear Rate increases when peak current and pulse on time are increased whereas there is no much change when pulse off time is increased. In another study conducted by **Muhamed Mehmedović et al [32],** they concluded that effect of white layer additional plastic deformation results in decrease of machined surface roughness compared to its expected value. On the basis of experimental work and presented methodology it is possible to generate white layer with followed properties: continuous existence along the machined surface, sufficient medium thickness, approximately uniform thickness along the machined surface, increased micro hardness compared to the raw material and sufficient bonding characteristics to the raw material.

J. Krawczyk et al [33] in their investigation concluded that tribological conditions under whichmetallurgical rolls operate favor the formation of the white layer on their surface. This layer can be readily formed on the surface of heat treated forged steel rolls. To avoid the consequences of the white layer formation on the rolls surface it is necessary to uniformly distribute the precipitates of secondary cementite in the material structure.

A. M. Nikalje et al [34] in their study found that discharge current, pulse on time, and pulse off time have been found to play significant role in EDM operations. Also, it was found that the optimal levels of the factors for SR and TWR are same but differs from the optimum levels of the factors for MRR and TWR. **Md. Ashikur Rahman Khan et al [35]** conducted a study to investigate the effect of the machining parameters on surface roughness and surface structure in EDM of Ti-5Al-2.5Sn Titanium. He concluded that surface roughness increases linearly as the peak current increases for copper and copper–tungsten electrodes. For copper and copper–tungsten electrodes, after the peak value of SR, the surface roughness decreases as the pulse-on time increases.

S. Rajesha et al [36] from their investigation found that the most dominating factors for MRR are the pulse current, duty factor. Hence in order to obtain high values of MRR while machining Inconel 718, pulse current and duty factor are suggested to hiher. Tool wear, thickness of the sputtered layer, and crack propagation on the tool were highly dominated by higher pulse current. **M.A. Ali et al. [37]** in his investigation found that the machine voltage is the less significant factor as compared to peak current. Higher the peak current and pulse on time level, the higher value MRR can be obtained. The changes of peak current and pulse on time may contribute to a great influence of MRR. It can also be concluded that a storage spark will have higher energy when increasing peak current, and subsequently more heat is generated and substantial quantity of heat utilized in material removal.

Subramanian Gopalakannan [38] observed that the output parameters such as material removal rate, electrode wear and surface roughness of EDM depends and increase with pulsating current. The results also revealed that higher material removal rate have been achieved while using copper electrode whereas copper-tungsten yielded lower electrode wear, better surface finish and higher dimensional accuracy. **K.S. Banker et al [39]** concluded that in the PMEDM, the floating particles accelerate the ignition process by creating higher discharge potential and it lowers the breakdown strength of the insulating dielectric fluid. Hence, MRR is increased, TWR is decreased and sparking efficiency is improved.

Ali. Moarrefzadeh [40] through their investigation concluded that the experimental values of MRR and EWR can be satisfactorily predicted by using the developed model and performing minimum number of experiments. Mathematical modeling of EDM hole drilling process by RSM technique can enable easy prediction of MRR and EWR values without performing unnecessary experiments.

2.2 PROBLEM FORMULATION

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

- To find influence on MRR with Ip, Ton and Toff.
- To find influence on TWR with Ip, Ton and Toff.
- To find influence on White layer thickness with Ip, Ton and Toff.

3

TAGUCHI APPROACH AND ANOVA

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.

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

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 beevaluated.
- Determine the number of levels for the process parameters and possible interactions betweenthe process parameters.
- Selecting appropriate taguchi orthogonal array and assigning the process parameters to theorthogonal 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.

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 ofS/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 andafter the experiment, Taguchi's loss function is used for estimating the potential cost saving fromthe improved product.

ADAVANTAGE 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:

- 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.
- 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.

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.

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.

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	5	7
2	Pulse-on-time	µsec	10	30	50
3	Pulse-off-time	µsec	10	30	50

Table 3.2: Experimentation L9 Orthogonal Array

S. No.	Ip	T on	T off
1	3	10	10
2	3	30	30
3	3	50	50
4	5	10	30
5	5	30	50
6	5	50	10
7	7	10	50
8	7	30	10
9	7	50	30

4

EXPERIMENTATION

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, 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

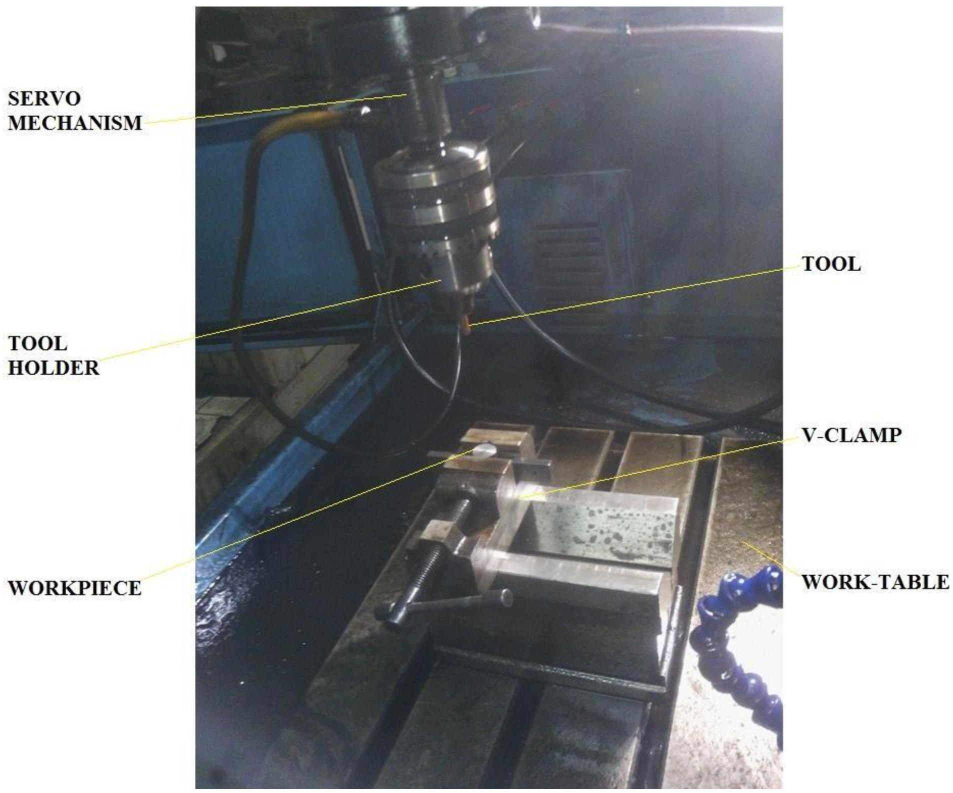


Figure 4.1: Machining the workpiece on EDM

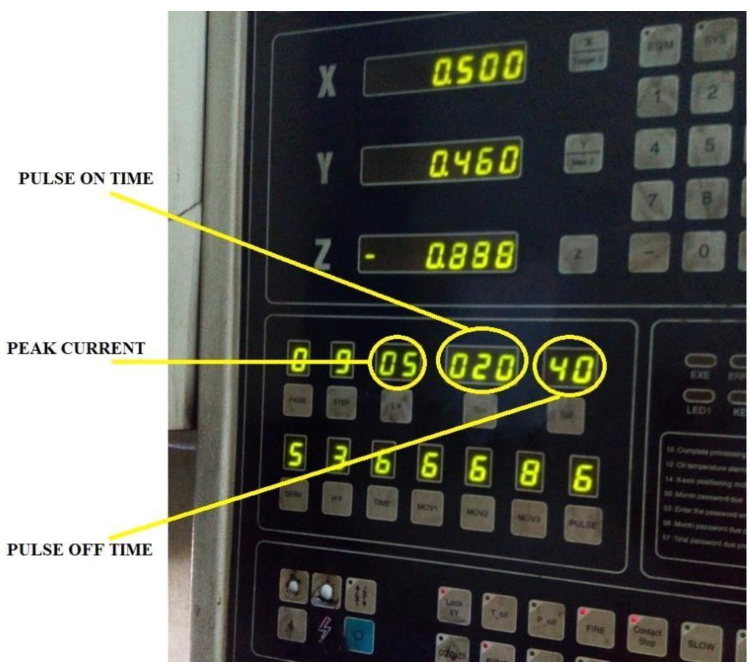


Figure 4.2 EDM Machine panel showing parameters (Setup for 4^{th} Experiment)

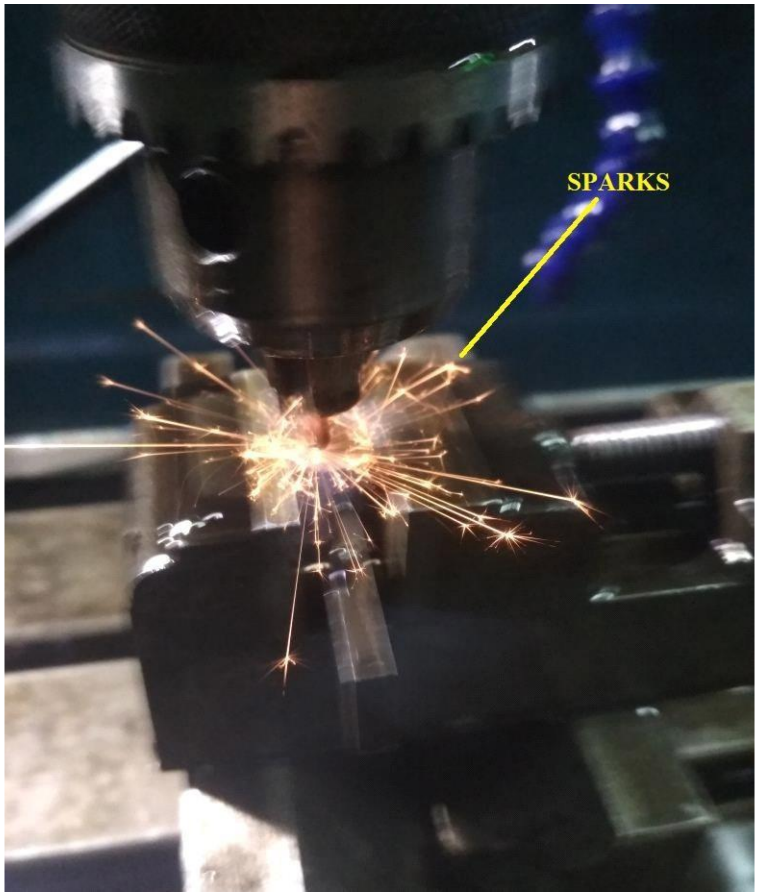


Figure 4.3 Sparks produced during EDM

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 toolsand 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 coolingmechanism 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 andproducts of decomposition.

9. It should be economical and easily available.

WORK PIECE MATERIAL

The material selected for the present work is EN-8 and the specimen made is of 5 mm thickness and 14 mm diameter. EN-8 is used for light stressed gears, crankshafts, connecting rods, axle beams, etc. Basically it is used for moderately stressed parts of vehicles and for general engineering works.

EN-8 is also known as 080M40 is an unalloyed medium carbon steel. It is of medium strength, having good tensile strength which is suitable for shafts, stressed pins, studs, keys, etc.

Table 4.2: Chemical composition of Work-piece (EN-8) by weight

Material	Fe	Mn	S	C	Si	P
% Composition	96.7	0.70	0.05	0.40	0.50	0.05

Table 4.3: Properties of EN-8

Density (g/cm^3)	Melting point (ºC)	Yeild strength (MPa)	Elastic modulus(GPa)	Possion's Ratio	Brinell Hardness
7.86	1421	465	190	0.29	205

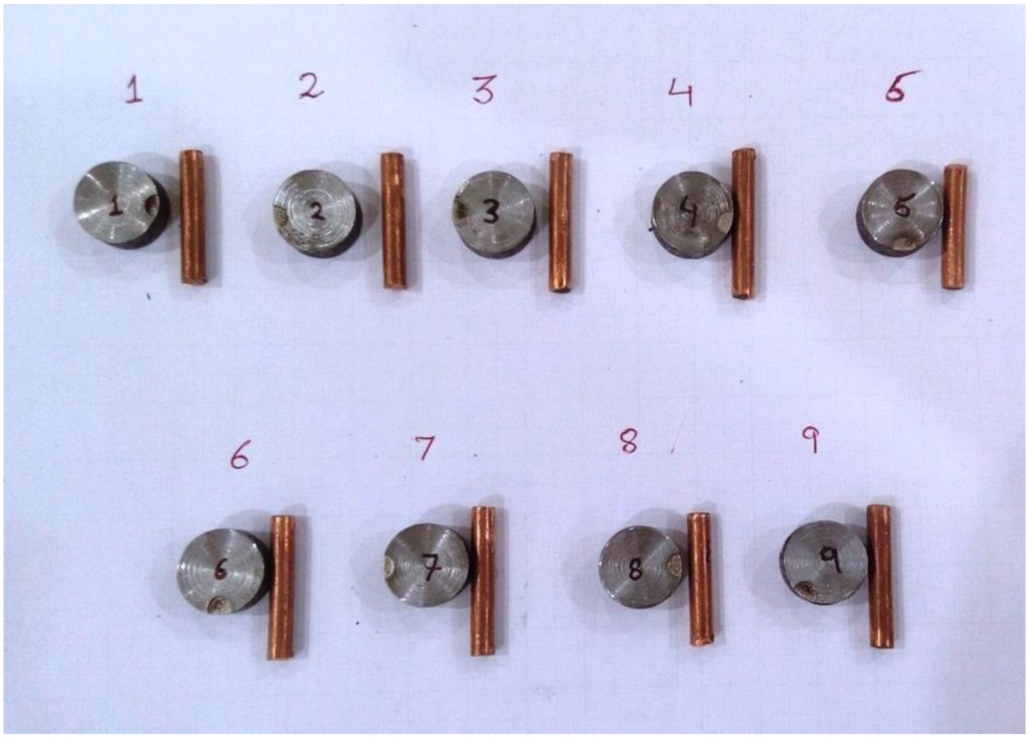


Figure 4.4: EN-8 machined work pieces

TOOL MATERIAL

The tool or electrode material used for this work is 100% Copper. The tool specimen was prepared of dimensions as 4mm length and 2.5 mm diameter. The density of pure copper used as tool is 8.96 g/cm^3.

Figure 4.5: A single Copper Tool

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.

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

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.

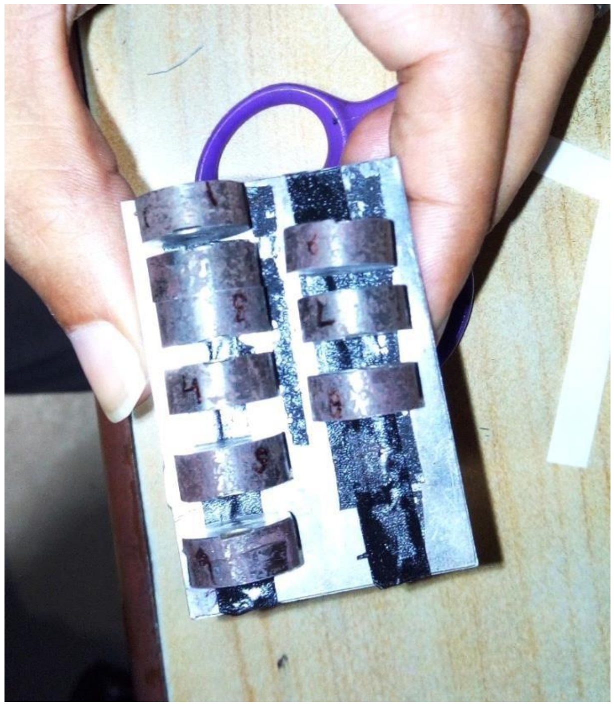
$$\mathbf{TWR} = \frac{\text{(Tool weight loss (gm)) X 1000}}{\text{Density (gm/cc) X Machining Time}}$$

WHITE LAYER THICKNESS

White layer thickness is measured by CARL ZIESS EVO 50 SEM machine which is available atDepartment of Material Science and Engineering, IIT Kanpur. Microstructures at SEM can be analyzed for its elemental composition in more detail using EDX system. It is a non-destructive analysis in which the elements and their concentration in the sample can be determined reasonably accurately.

Figure 4.6: 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 BSD in all modes - quadrant semiconductor diode

Figure 4.7: Work-piece setup for SEM

SPECIFICATION OF CARL ZIESS EVO 50 SEM MACHINE

5

RESULT AND DISCUSSION

RESULT AND DISCUSSION

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

Exp. No	Ip	Ton	Toff	MRR(mm³/min)
1	3	10	10	0.493
2	3	30	30	0.272
3	3	50	50	0.379
4	5	10	30	0.829
5	5	30	50	0.833
6	5	50	10	3.319
7	7	10	50	2.145
8	7	30	10	3.326
9	7	50	30	5.118

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

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 rateLARGER 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(mm^3/min)	Signal to noise ratio (db)
1	0.493	-6.1431
2	0.272	-11.3086
3	0.379	-8.4272
4	0.829	-1.6289
5	0.833	-1.5871
6	3.319	10.4201
7	2.145	6.6285
8	3.326	10.4384
9	5.118	14.1820

Calculation of Mean S/N ratio for MRR

Mean S/N ratio is calculated by using following formula

$$\mathbf{nf_i = (nf_1 + nf_2 + nf_3)/3}$$

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 pulse off time are less effective as compared to peak current.

Table 5.3 Calculation of mean S/N ratio for MRR

Level	**Ip**	**Ton**	**Tof**
1	-8.6263	-0.3811	4.9052
2	2.4014	-0.8191	0.4148
3	10.4163	5.3916	-1.1286
Delta	19.0426	6.2107	6.0338
Rank	**1**	**2**	**3**

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

Analysis of Variance for MRR

The following table shows ANOVA of MRR conducted on MINITAB . The result shows that thecontribution of current is most and is 63.53%.

Table 5.4 ANOVA of MRR

Source	**DOF**	**SS**	**Adj MS**	**F Value**	**Contribution**
Ip	2	15.0423	7.5511	24.20	63.53%
Ton	2	5.4188	2.7094	8.72	22.88%
Toff	2	2.5924	1.2962	4.17	10.94%
Error	2	0.6216	0.3108		2.62%
Total	8	23.6750			100%

At least 95% confidence

CALCULATIONS OF ANOVA

Table 5.5 Values of MRR corresponding to different levels of Ip

Ip Levels	**Value 1**	**Value 2**	**Value 3**
3	0.493	0.272	0.379
5	0.829	0.833	3.319
7	2.145	3.326	5.118

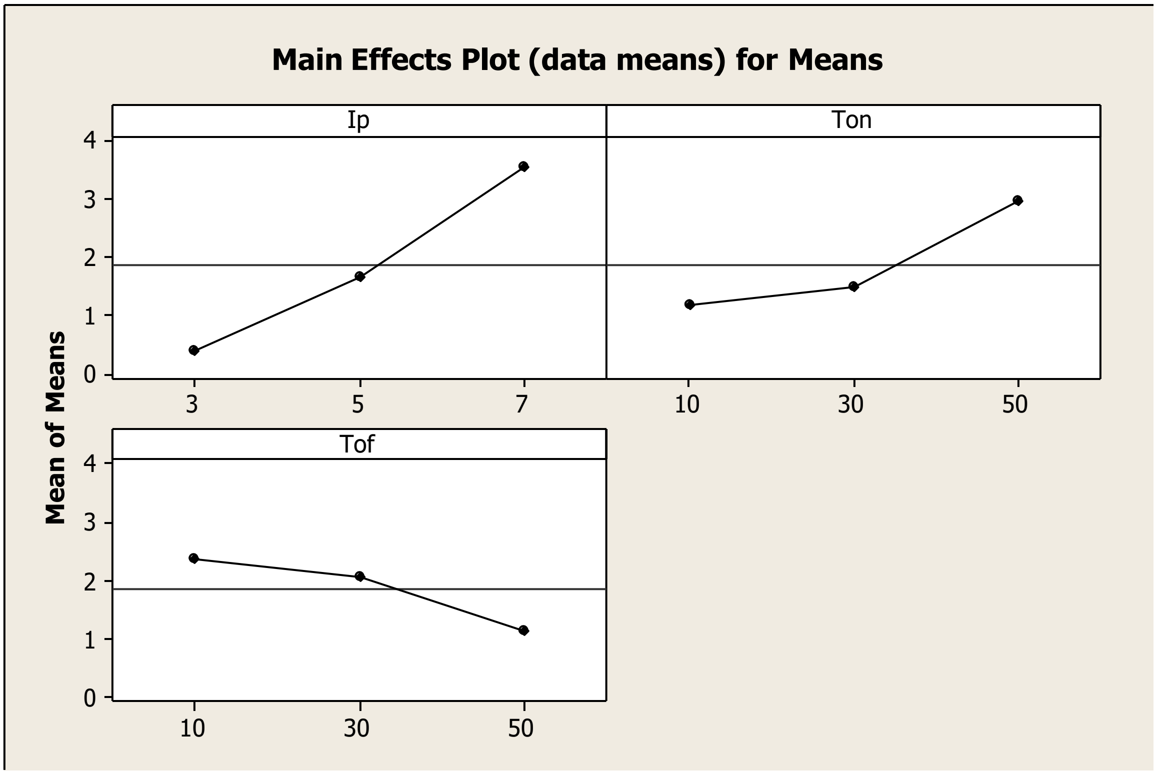


Figure 5.1: Main effect plot for MRR

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, both these parameters have major influence on MRR with increase in the level of peak current and pulse on time, the MRR is observed to follow an increasing trend. It probably occurred because the intensity of spark is more at higher level of parameters and hence MRR increases.

MRR is observed to be follow a decreasing trend with pulse off time and it is the least influencing parameter for MRR and has only 10.94% contribution.

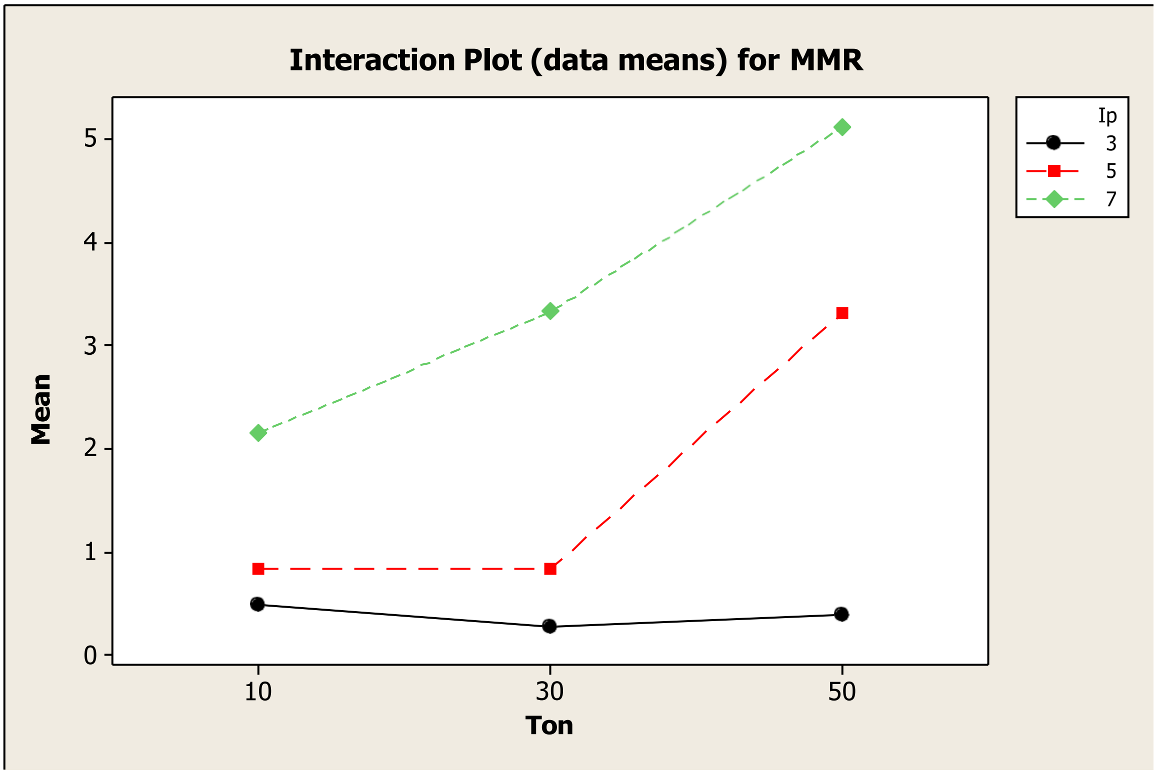


Figure 5.2: Interaction plot for parameters and MRR

Figure 5.3 depicts the interaction plot between MRR and pulse on time at different levels of peak current. The plot elucidates that the material removal rate increases with EDM parameters at all levels. At low level of peak current, there is no much influence of pulse on time on MRR. On increasing the level of peak current, the MRR increases with pulse on time.

Optimal Levels of Parameters for MRR

- **Peak Current : 7A**
- **Pulse on Time : 50µsec**
- **Pulse off Time : 10µsec**

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 5.6: Calculation for Tool Wear Rate

Exp. No	Ip	Ton	Toff	TWR(mm³/min)
1	3	10	10	0.134
2	3	30	30	0.075
3	3	50	50	0.238
4	5	10	30	0.233
5	5	30	50	0.490
6	5	50	10	2.870
7	7	10	50	0.479
8	7	30	10	0.972
9	7	50	30	3.345

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 5.7 Calculation of S/N ratio for TWR

S.No	TWR(mm^3/min)	Signal to noise ratio (db)
1	0.134	17.4579
2	0.075	22.4988
3	0.238	12.4685
4	0.233	12.6529
5	0.490	6.1961
6	2.870	-9.1576
7	0.479	6.3933
8	0.972	0.2467
9	3.345	-10.4879

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 5.8 Calculation of mean S/N ratio for TWR

Level	Ip	Ton	Toff
1	17.475	12.168	2.849
2	3.230	9.647	8.221
3	-1.283	-2.392	8.353
Delta	18.758	14.560	5.504
Rank	**1**	**2**	**3**

Analysis of Variance for TWR

Table 5.9 ANOVA of TWR

Source	DOF	SS	Adj MS	F Value	Contribution
Ip	2	3.3620	1.6810	2.85	27.33%
Ton	2	6.2314	3.1157	5.29	50.66%
Toff	2	1.5283	0.7641	1.30	12.42%
Error	2	1.1780	0.5890		9.57%
Total	8	12.2998			100%

At least 95% confidence

Optimal Levels of Parameters for TWR

- **Peak Current : 3A**
- **Pulse on Time : 10µsec**
- **Pulse off Time : 50µsec**

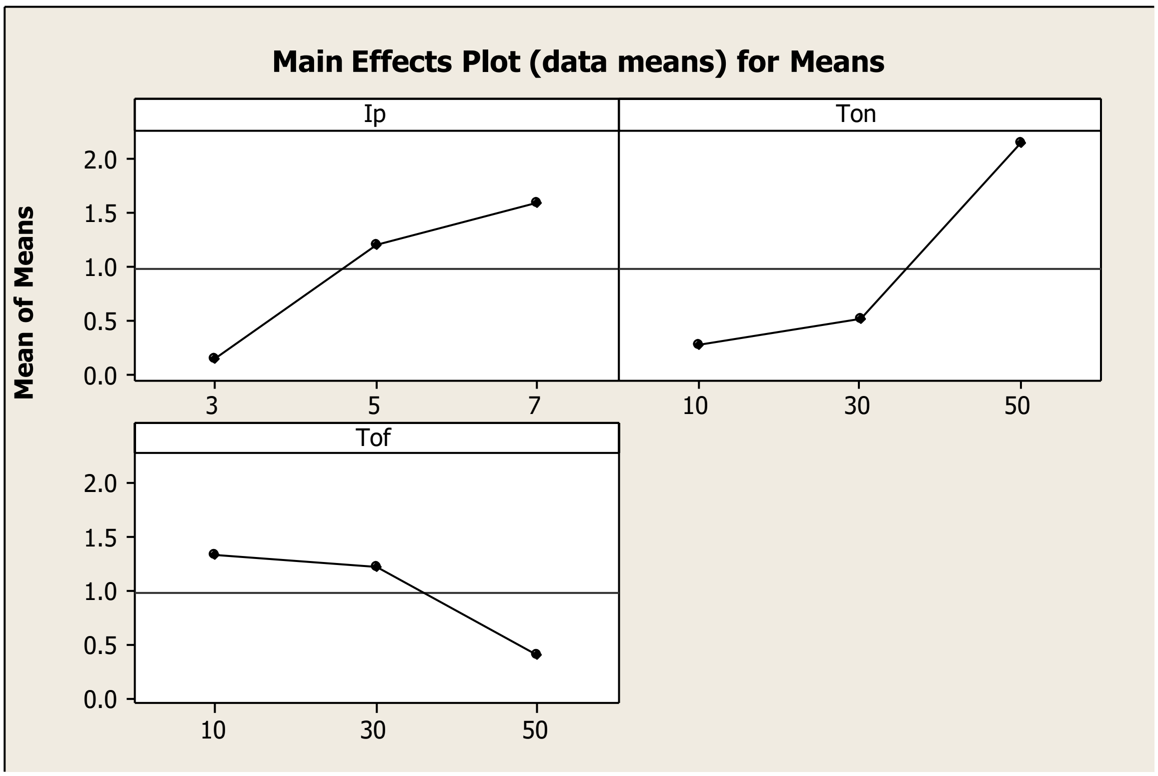


Figure 5.3: Main effect plot for TWR

The figure 5.5 illustrates that the tool starts to degrade with increase in levels of peak current and pulse on time while with pulse off time reverse trend is followed. This is similar to the case of MRR. Since pulse on time and peak current are the most influencing parameters, hence the plot obtained for them are showing increasing trend. Pulse on time is the major influencing parameter for tool wear rate with a contribution of 50.66%.

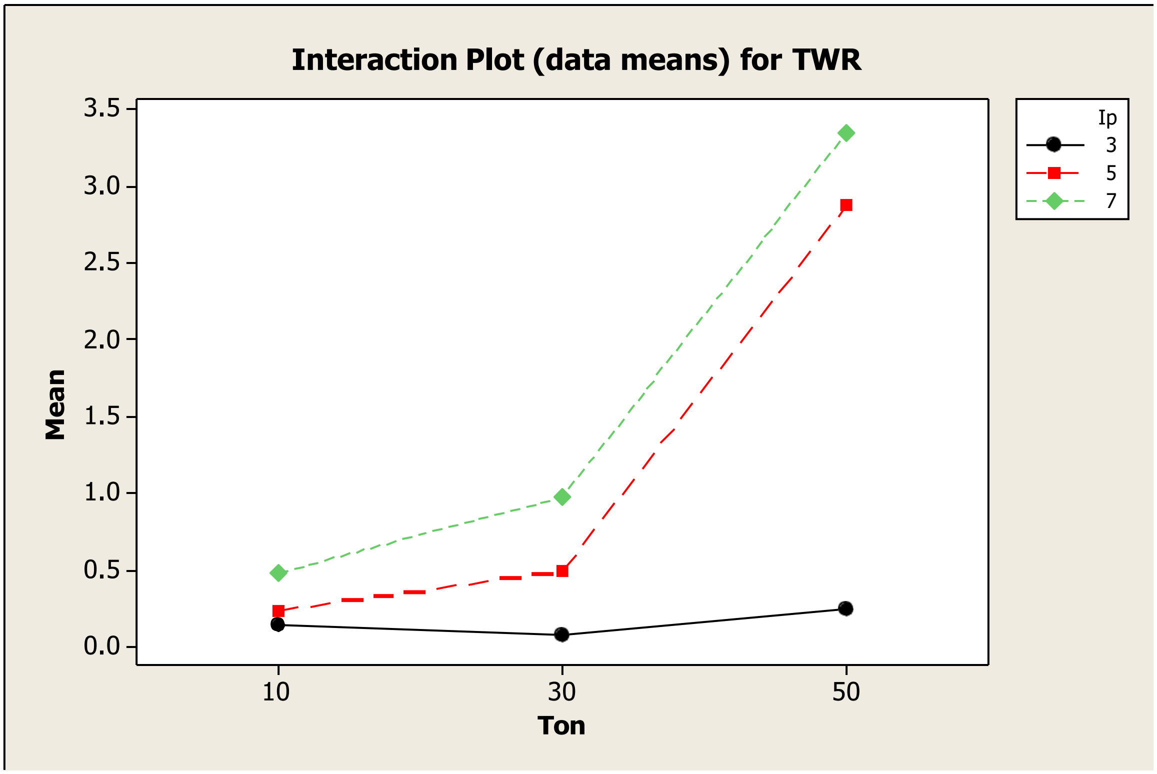


Figure 5.4: Interaction plot for parameters and TWR

Figure 5.4 depicts the interaction plot between TWR and current at different levels of pulse on time. The plot elucidates that the tool wear rate is initially not affected by current at lower level of pulse on time. When the value of pulse on time is increased, there is slight increase in TWR with current. At higher level of pulse on time, current have much influence on TWR.

CALCULATION FOR WHITE LAYER THICKNESS

White layer (WL) is a re-deposited or recast layer caused by rapid quenching in dielectrics in EDM. Unlike the uniform solid WL by a mechanical cutting, the WL in EDM at main cutting mode isa bi-layer structure. The upper region of the WL is a porous structure, which consists of re-deposition of evaporated materials in the gap. The lower part of the WL is a solid structure, which recasts fromthe molten materials after the plasma channel collapse. Moreover, the microstructure of EDM WL is dramatically different from the bulk material as the result of complex phase transformation during rapid quenching. The white layer of EDMed steel mainly consisted of dendritic and columnar structures which were orientated in the same direction.

Table 5.9 shows the calculation of Average White layer thickness varying with current, pulse on time and pulse off time.

Table 5.10: Calculation for Average White layer thickness

Exp. No	**Ip**	**Ton**	**Toff**	**Average White Layer Thickness (μm)**
1	3	10	10	46.30
2	3	30	30	47.10
3	3	50	50	53.51
4	5	10	30	57.20
5	5	30	50	65.00
6	5	50	10	79.70
7	7	10	50	84.25
8	7	30	10	96.25
9	7	50	30	159.80

Calculation of S/N ratio for White Layer Thickness

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 White Layer Thickness SMALLER IS BETTER condition is opted. Smaller the White Layer Thickness, better is the tolerance achieved.

The equation for the calculation of S/N ratio for White Layer Thickness is:

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

Table 5.11 Calculation of S/N ratio for White Layer Thickness

S.No	Average White Layer Thickness (µm)	Signal to noise ratio (db)
1	46.30	-33.3116
2	47.10	-33.4604
3	53.51	-34.5687
4	57.20	-35.1479
5	65.00	-36.2583
6	79.70	-38.0292
7	84.25	-38.5114
8	96.25	-39.6680
9	159.80	-44.0715

Calculation of Mean S/N ratio for White Layer Thickness

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 5.12 Calculation of mean S/N ratio for White Layer Thickness

Level	Current	Pulse on time	Pulse off Time
1	-33.78	-35.66	-37.00
2	-36.48	-36.46	-37.56
3	-40.75	-38.89	-36.45
Delta	6.96	3.23	1.11
Rank	**1**	**2**	**3**

Analysis of Variance for White Layer Thickness

ANOVA for surface roughness is given in the following table-

Table 5.13 ANOVA of White Layer Thickness

Source	DOF	SS	Adj MS	F Value	Contribution
Current	2	6619.8	3309.9	7.70	64.84%
Pulse on Time	2	2074.6	1037.3	2.41	20.32%
Pulse off Time	2	654.9	327.4	0.76	6.41%

Error	2	859.6	429.8		8.42%
Total	8	10208.9			100%

At least 95% confidence

Optimal Levels of Parameters for White Layer Thickness

- **Peak Current : 3A**
- **Pulse on Time : 10µsec**
- **Pulse off Time : 50µsec**

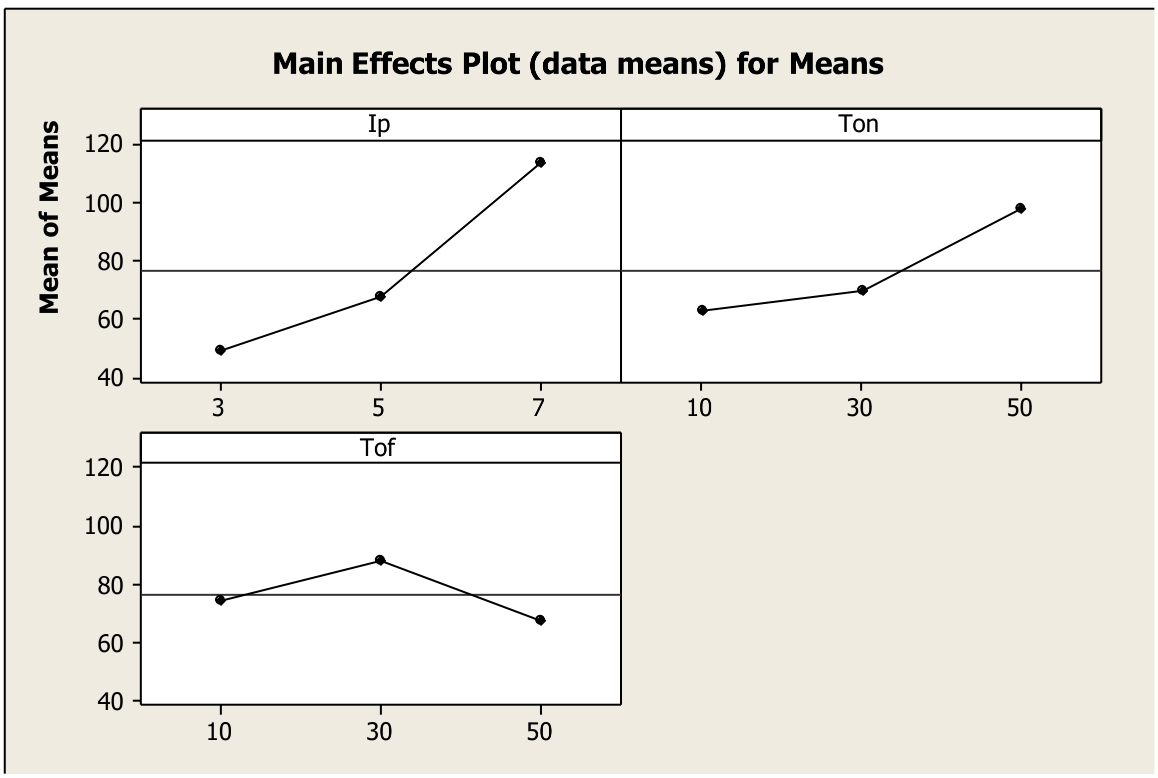


Figure 5.5 Main effect plot for White Layer Thickness

The above graph shows the effect of input parameters on White layer thickness. By increasing the peak current and pulse on time, the white layer thickness increases. Peak current is the most dominating factor for white layer thickness with a contribution of 64.84% and has major influence on it. Higher intensity sparks are generated at higher levels of peak current, hence influence of peak current is highest and white layer thickness increases due to sudden quenching with increase in the value of peak current. Pulse on time is found to be the second most dominating parameter for white layer thickness with a contribution of 20.32%. With pulse off time, the white layer formation first increases. On further increase in pulse off time value, the white layer formation tends to decrease. Pulse off time has least influence on white layer thickness formation and has a contribution of only 6.41%.

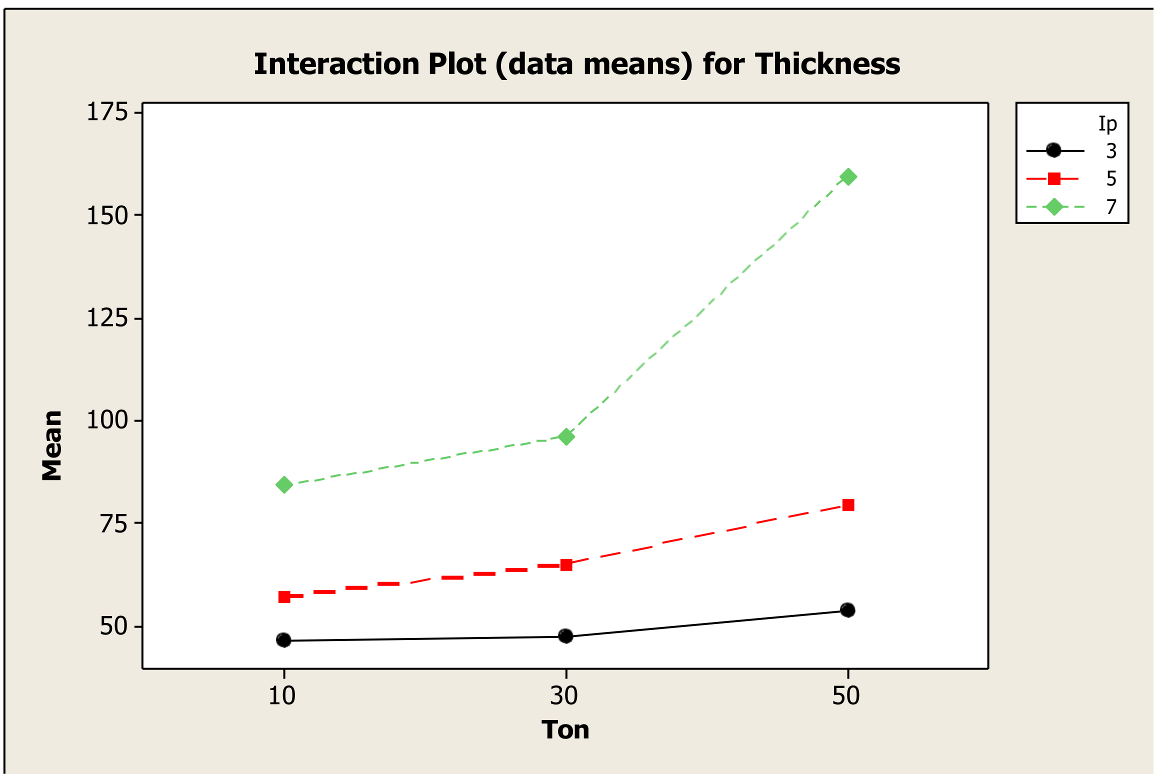


Figure 5.6: Interaction plot for parameters and White Layer Thickness

Figure 5.6 depicts the interaction plot between White layer thickness and pulse on time at different levels of peak current. The plot elucidates that the Hole Enlargement is influenced by pulse on time at each level of peak current. At lower level of peak current, the influence of pulse on time is almost negligible on white layer formation. When the value of peak current is increased, there is much increase in white layer formation with pulse on time.

SEM FIGURES OF WHITE LAYER THICKNESS

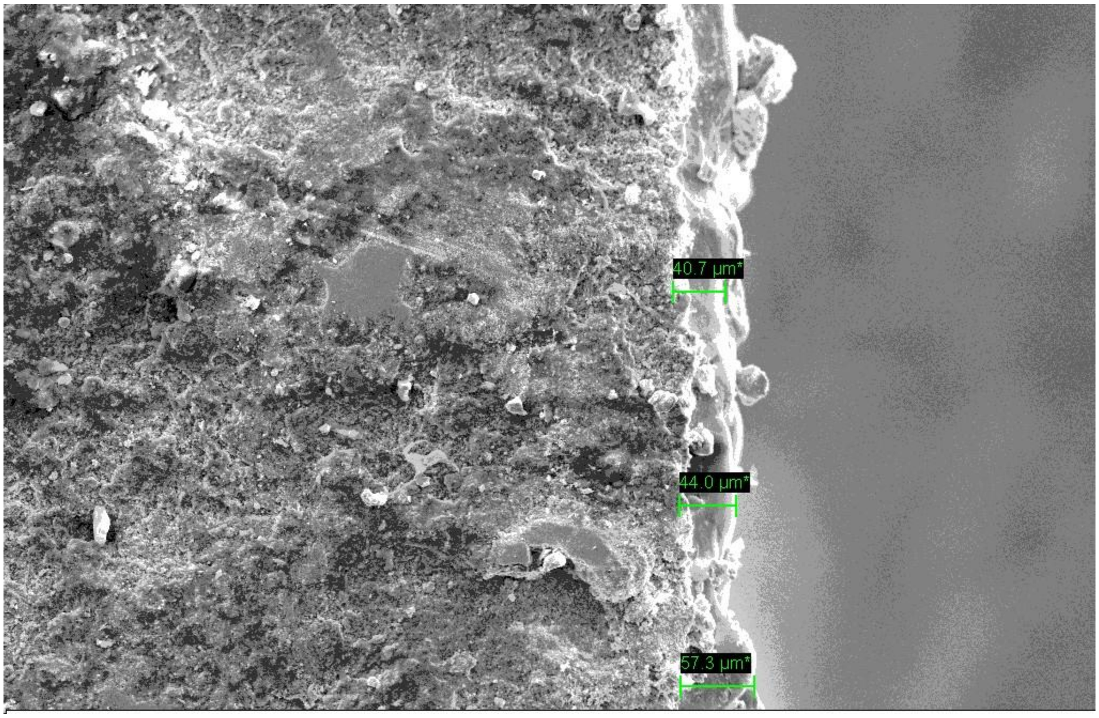


Figure 5.7: SEM of Sample 1

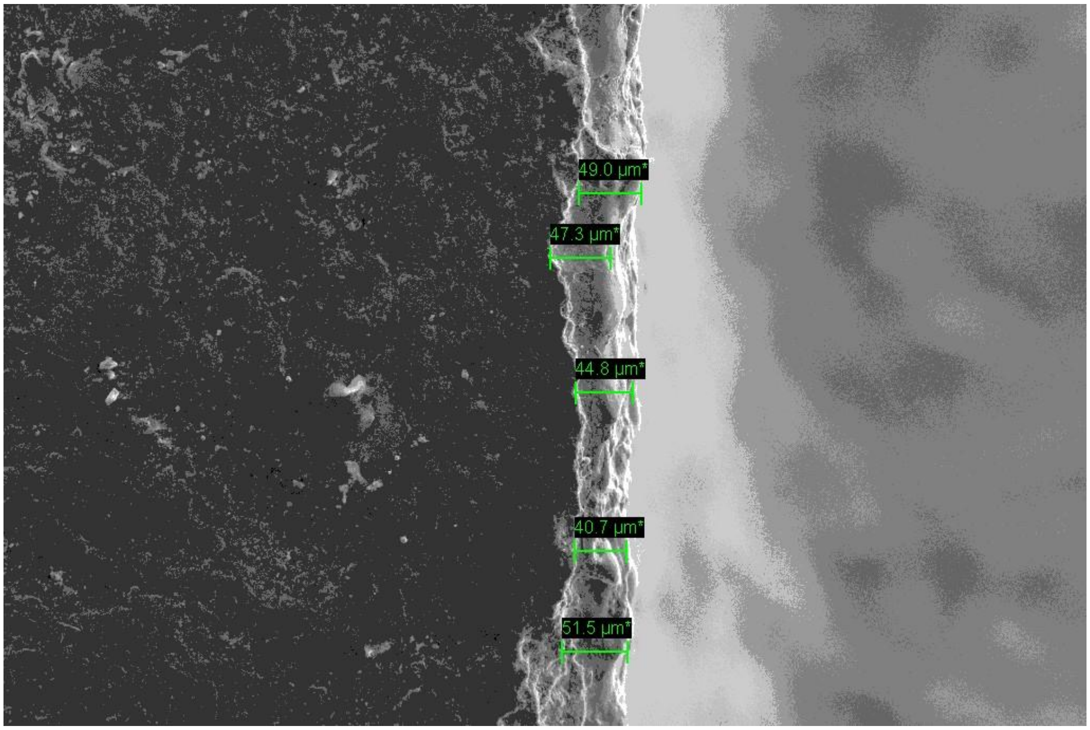


Figure 5.8: SEM of Sample 2

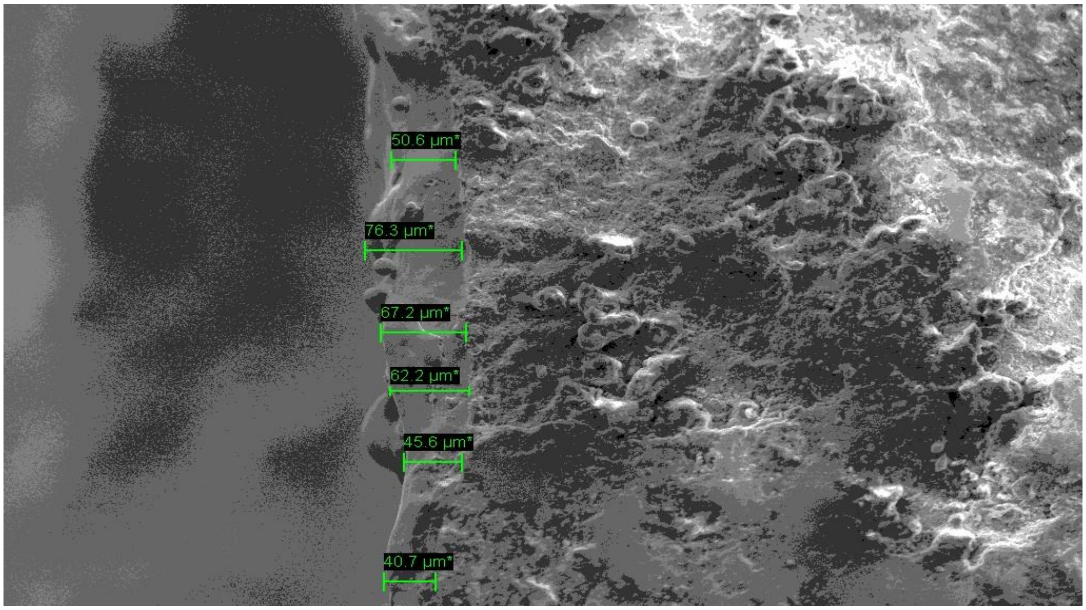


Figure 5.9: SEM of Sample 3

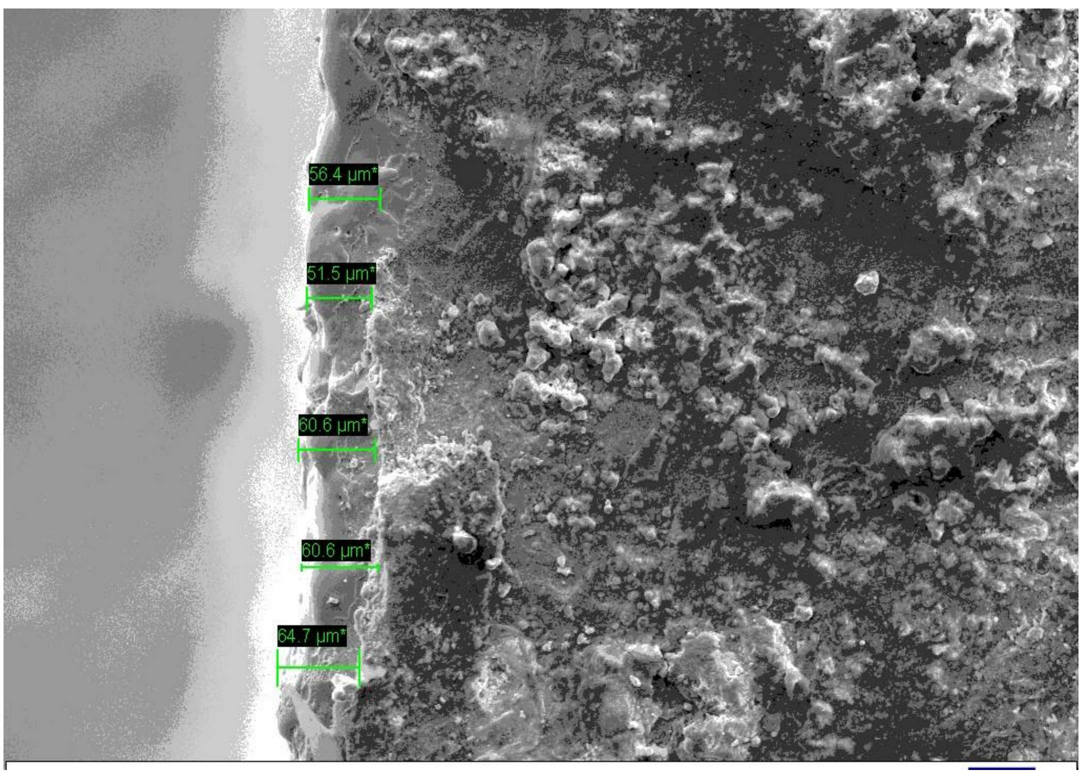


Figure 5.10: SEM of Sample 4

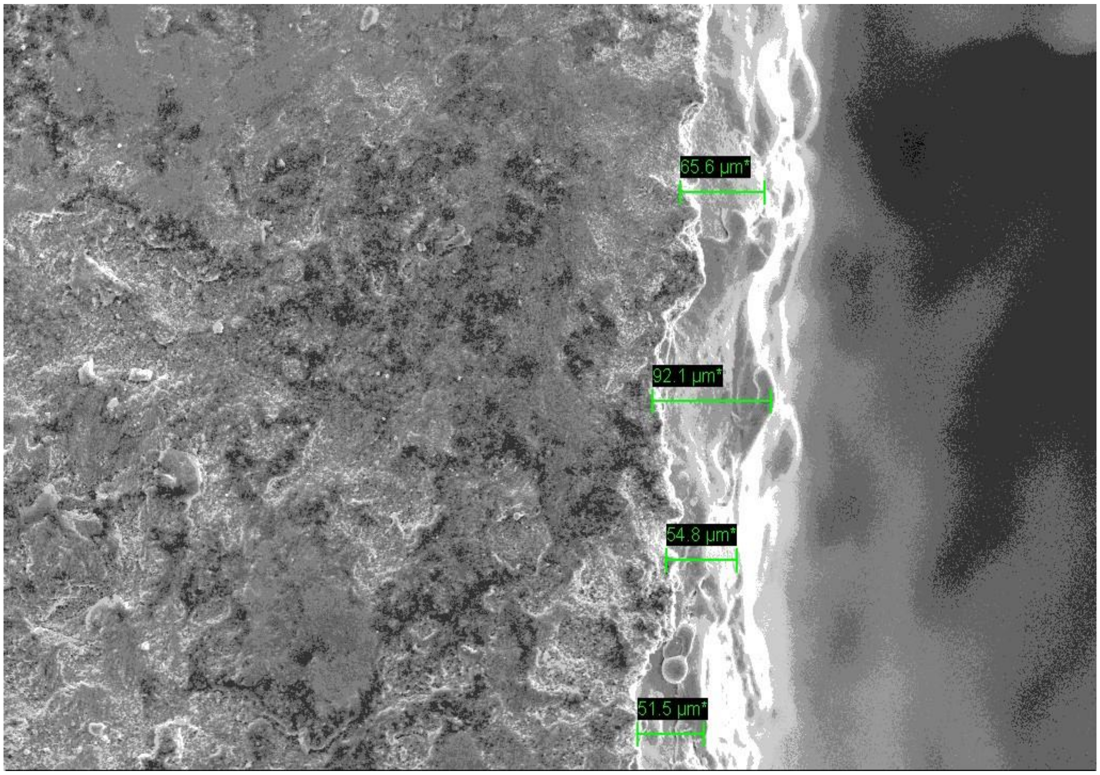


Figure 5.11: SEM of Sample 5

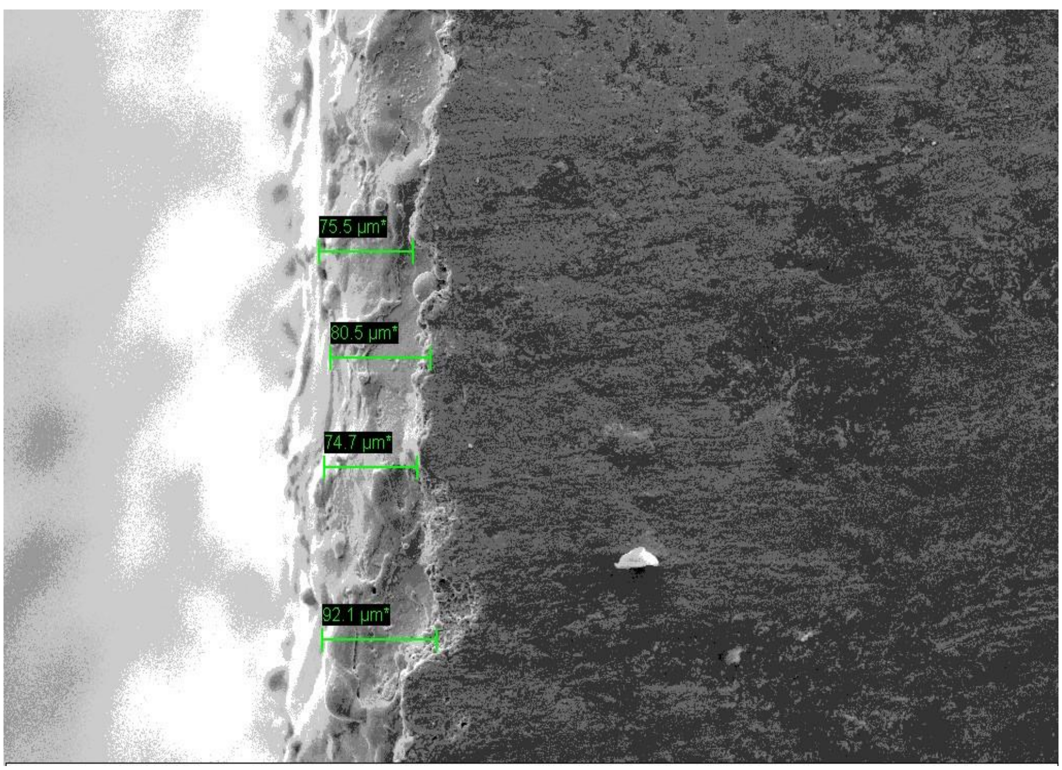


Figure 5.12: SEM of Sample 6

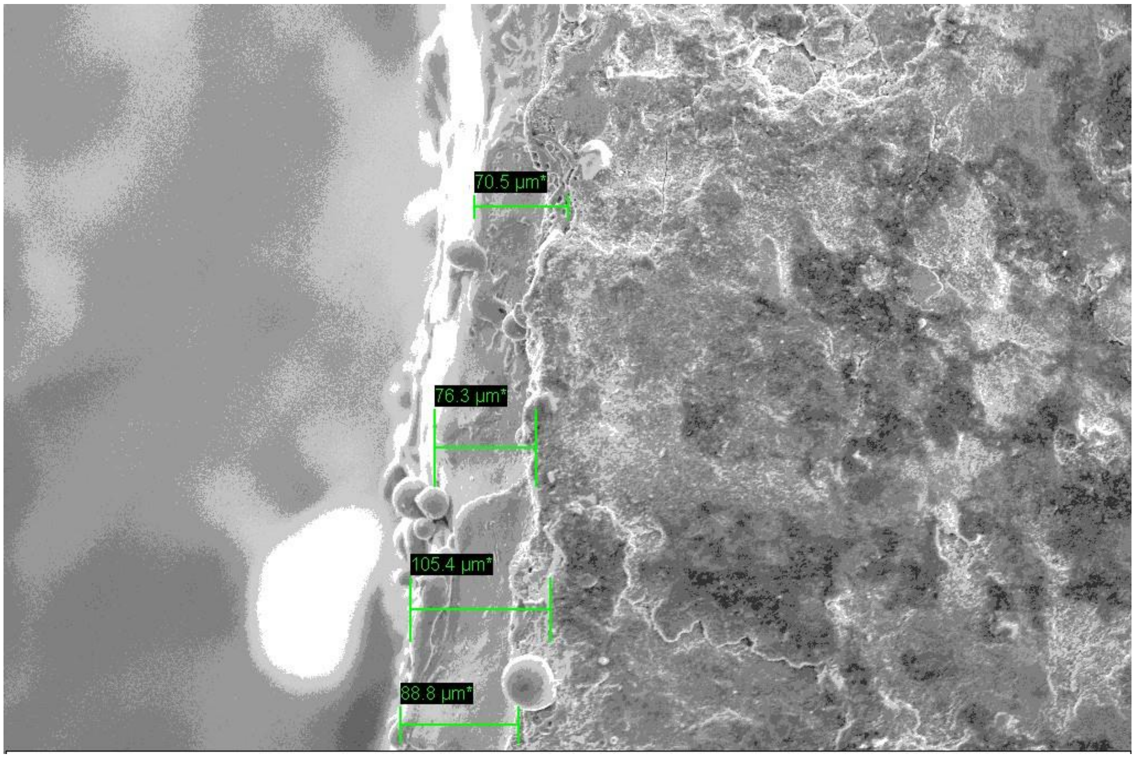


Figure 5.13: SEM of Sample 7

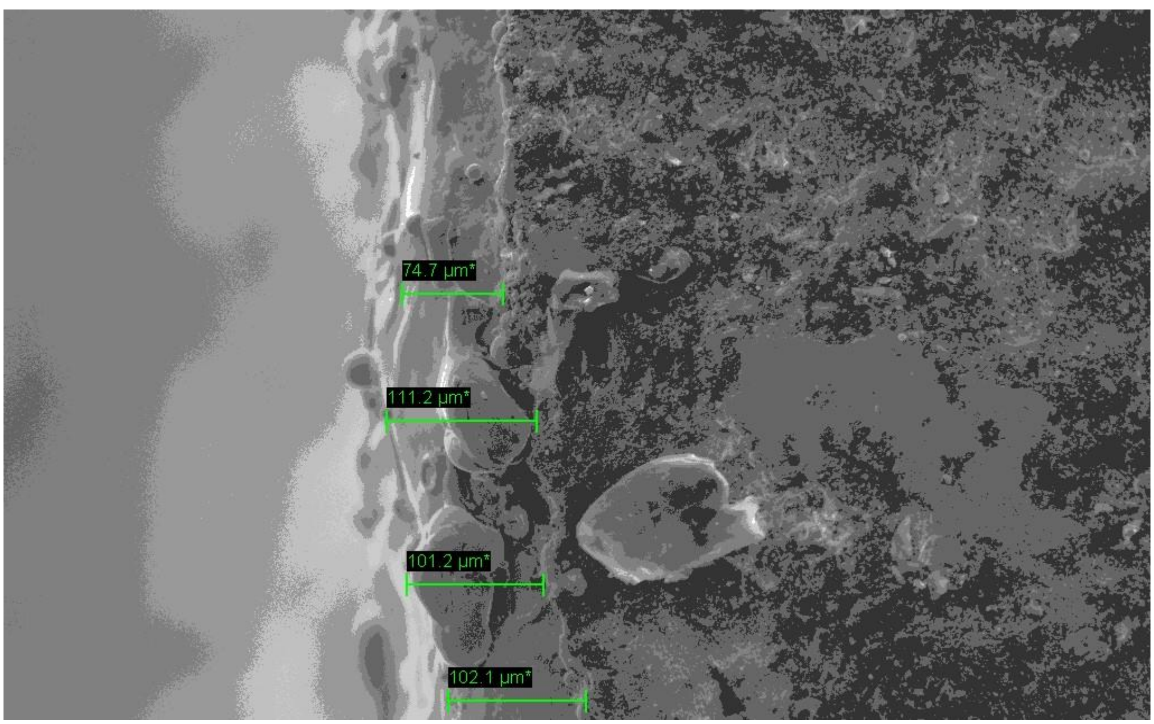


Figure 5.14: SEM of Sample 8

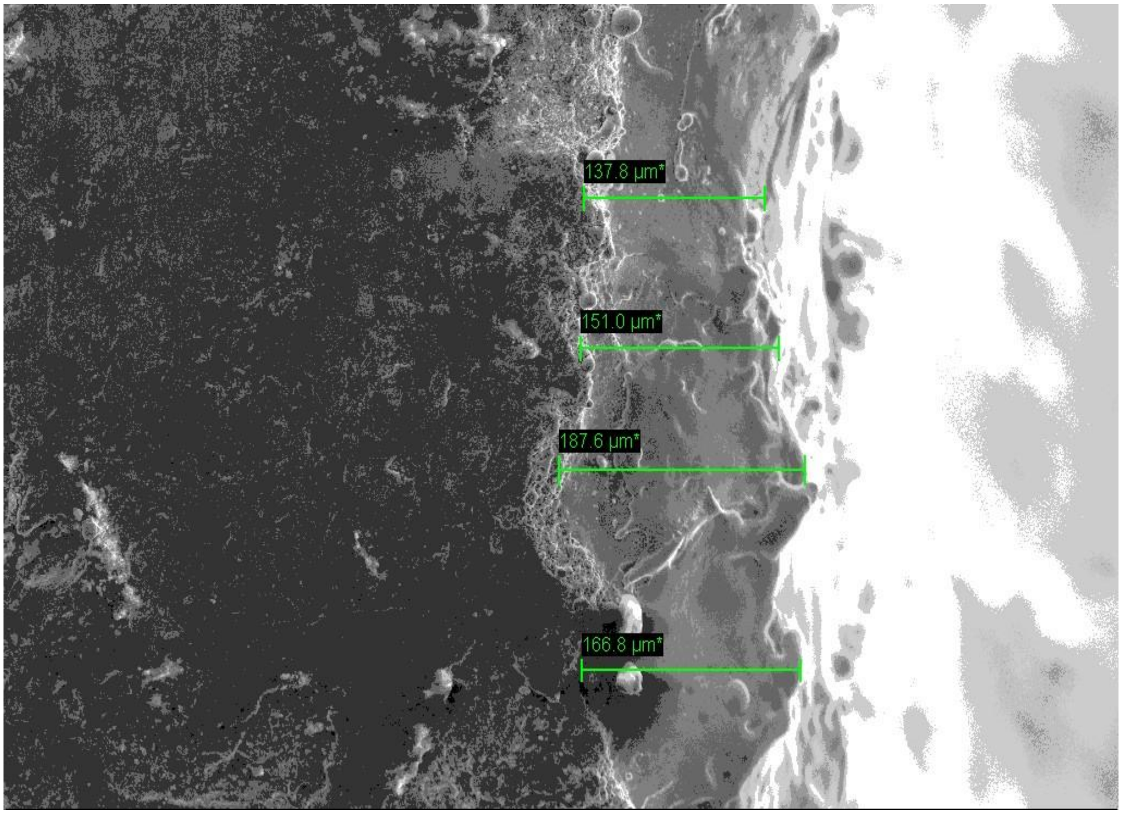


Figure 5.15: SEM of Sample 9

CONFIRMATION TEST

Confirmation tests have been performed for MRR, TWR and White layer Thickness withtheir optimum levels of process variables.

Table 5.14: Confirmation of expected and actual values of MRR

ExperimentNo.	**Optimum Machining Parameters**			**MRR (gm/min)**	
	Current (A)	**Pulse on Time (µsec)**	**Pulse off Time (µsec)**	**Actual**	**Expected**
1	**7**	**50**	**10**	**4.742**	**4.521**
				Error (%)	**4.66%**

Table 5.15: Confirmation of expected and actual values of TWR

ExperimentNo.	**Optimum Machining Parameters**			**TWR**	
	Current (A)	**Pulse on Time (µsec)**	**Pulse off Time (µsec)**	**Actual**	**Expected**
1	**3**	**10**	**50**	**0.197**	**0.186**
				Error (%)	**5.58%**

Table 5.16: Confirmation of expected and actual values of White Layer Thickness

Experim entNo.	Optimum Machining Parameters			White Layer Thickness	
	Current (A)	Pulse on Time (µsec)	Pulse off Time (µsec)	Actual	Expecte d
1	3	10	50	50.02	50.76
				Error (%)	1.48%

6

CONCLUSIONS

The present experimental study describes the optimization of input machining parameters in Electrical Discharge Machining of EN-8 with copper electrode using L9 orthogonal array of Taguchi method. Factors like Current, Pulse on Time and Pulse off timer and their interactions were found. These results show the performance of parameters at different levels to optimize the MRR, TWR and White Layer Thickness. Following conclusions are made:

- Material removal rate increases with peak current and pulse on time and both the parameters have major influence on MRR. MRR is observed to follow an increasing trend with increase in the level of peak current and pulse on time. It probably occurred because the intensity of spark is more at higher level of parameters and hence MRR increases.
- Peak Current is the major influencing parameter for mrr with a contribution of 63.53%.
- MRR is observed to be follow a decreasing trend with pulse off time and it is the least influencing parameter for MRR and has only 10.94% contribution.
- The same behavior of parameters is also notice for tool wear rate. Tool starts to degrade with increase in levels of peak current and pulse on time while with pulse off time reverse trend is followed.
- Pulse on time is the major influencing parameter for tool wear rate with a contribution of 50.66%.
- By increasing the peak current and pulse on time, the white layer thickness increases. Peak current is the most dominating factor for white layer thickness with a contribution of 64.84% and has major influence on it. It is usually due to higher intensity sparks generated at higher levels of peak current, hence influence of peak current is highest.

- White layer thickness increases due to sudden quenching with increase in the value of peak current.
- Pulse on time is found to be the second most dominating parameter for white layer thickness with a contribution of 20.32%.
- With pulse off time, the white layer formation first increases but on further increase in pulse off time value, the white layer formation tends to decrease. Pulse off time has least influenceon white layer thickness formation and has a contribution of only 6.41%.

7

REFERENCES

[1] 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.

[2] 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.

[3] 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.

[4] 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.

[5] 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.

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

[7] 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.

[8] 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.

[9] **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.

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

[11] **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, February2014.

[12] **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.

[14] **K.H. Ho and S.T. Newman**, "State of the art of electrical discharge machining (EDM)",International Journal of Machine Tools and Manufacture 43 (2003) 1287-1300.

[15] **Dhirendra nath mishra, Aarti Bhatia, Vaibhav Rana,** "Study on Electro Discharge Machining (Edm)", The International Journal Of Engineering And Science (IJES) Volume3 Issue 2 Pages 24-35 2014, ISSN(e): 2319 – 1813 ISSN(p): 2319 – 1805.

[16] **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.

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

[18] Kuldeep Ojha, R. K. Garg, K. K. Singh ,“MRR Improvement in Sinking Electrical Discharge Machining: A Review”, Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No.8, pp.709-739, 2010.

[19] 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.

[20] 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.

[21] 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. **[22]Sushil Kumar Choudhary and Dr. R.S Jadoun ,** “Current Advanced Research Development ofElectric Discharge Machining (EDM): A Review”, International Journal of Research in Advent Technology, Vol.2, No.3, March 2014 E-ISSN: 2321-9637.

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

[24] 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.

[25] 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).

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

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

[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.

[30] Satpal Singh and C.S. Kalra,"Experimental Study of PMEDM on EN 24 Steel withTungsten Powder in Dielectric", International Journal on Emerging Technologies 5(1): 153-160(2014)

[31] Y N. Annamalai, V. Sivaramakrishnan, N.Baskar, "Response Surface Modeling of Electric Discharge Machining ProcessParameters for EN 24 Low Alloy Steel" 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th–14th, 2014.

[32] MuhamedMehmedović, SabahudinEkinović, Emir Šarić, Samir Butković, "Methodology for the white layer formation on the machined surface during longitudinal turning of hardened steels" 17th International Research/Expert Conference"Trends in the Development of Machinery and Associated Technology"TMT 2013, Istanbul, Turkey, 10-11 September 2013.

[33] J. Krawczyk, J. Pacyna"Effect of tool microstructure on the white layer formation", Journal of achivements in material and manufacturing engineering, VOLUME 17ISSUE 1-2July-August2006.

[34] A. M. Nikalje& A. Kumar & K. V. SaiSrinadh, "Influence of parameters and optimization of EDM performance measures on MDN 300 steel using Taguchi method " Int J AdvManufTechnol (2013) 69:41–49, Springer-Verlag London 2013.

[35] Md. Ashikur Rahman Khan & M. M. Rahman &K. Kadirgama, "An experimental investigation on surface finish in die-sinking EDM of Ti-5Al-2.5Sn" Int J AdvManufTechnol (2015) 77:1727–1740, Springer-Verlag London 2014.

[36] S. Rajesha, A.K. Sharma, and Pradeep Kumar, "On Electro Discharge Machining of Inconel 718 with Hollow Tool", Journal of Materials Engineering and Performance 882-volume 21 (6) June 2012.

[37] M.A. Ali, M. Samsul, N.I.S. Hussein, M. Rizal, R. Izamshah,M. Hadzley, M.S. Kasim, M.A. Sulaiman and S. Sivarao, "The Effect of Edm Die-sinking Parameters on Material Removal Rate of Beryllium Copper Using Full Factorial Method", Middle-East Journal of Scientific Research 16 (1): 44-50, 2013 ISSN 1990-9233.

[38] Subramanian Gopalakannan, ThiagarajanSenthilvelan, "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 July 2012.

[39] K.S. Banker, S. P. Parmar, B. C. Parekh, “Review to Performance Improvement of Die Sinking EDM Using Powder Mixed Dielectric Fluid” International journal of research in modern engineering and emerging technology, vol. 1, Issue: 3, April – 2013 (IJRMEET) ISSN: 2320-6586.

[40] Ali. Moarrefzadeh, “finite-element simulation of electricaldischarge machining (edm) process”, International journal of multidisciplinary sciences and engineering, vol. 2, no. 5,august 2011

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 09 Issue: 07 | July 2022 www.irjet.net p-ISSN: 2395-0072

"Experimental Investigation on EDM of EN-8 Using Copper Tools"

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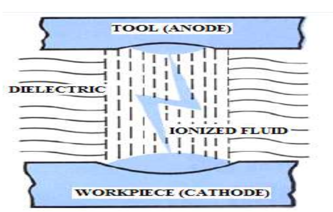
Abstract - EDM machine is a non-conventional machine which is used to cut alloy materials with high hardness, impact resistance and toughness. It can cut complex contours which are difficult to be machined by conventional cutting methods. The present investigation is conducted on EDM is performed on EN-8 with copper as electrode to establish the relationship between process parameters of EDM on material removal rate, tool wear rate and white layer thickness. The investigation concluded that material removal rate, tool wear rate and white layer thickness were majorly influenced by the peak current and pulse on time. Pulse off time was found to be the least dominating parameter for all the performance measures.

1.INTRODUCTION

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.



1.

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 too),usually graphite or copper, is in shape of a cavity to be produced on workpiece which is fed verticaaly 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 maintains 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..

7 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	5	7
2	Pulse-on-time	μsec	10	30	50
3	Pulse-off-time	μsec	10	30	50

Experimental Investigation on EDM of EN-8 Using Copper Tools

By PAWAN BANSAL

MTP1

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