

Thesis
On
**OPTIMIZATION OF PROCESS PARAMETERS IN POWDER
MIXED EDM OF H21 HOT DIE STEEL**

*Submitted in partial fulfillment of the requirement for the award of
degree of*

**MASTER OF ENGINEERING
IN
PRODUCTION & INDUSTRIAL ENGINEERING**

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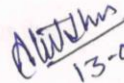
DECLARATION

I hereby declare that the thesis entitled '**OPTIMIZATION OF PROCESS PARAMETERS IN POWDER MIXED EDM OF H21 HOT DIE STEEL**' is an authentic record of my study carried out as requirement for the award of degree of **Master of Engineering in Production and Industrial Engineering** at **Thapar University, Patiala** under the supervision of **Mr. Atul Sharma, Lecturer**, Thapar University, Patiala during July 2012 to July 2013. The matter embodied in this report has not been submitted in part or full to any other university or institute for award of any degree.

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It is certified that the above statement made by the student is correct to best of my knowledge and belief.



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Lastly, and the most importantly, I wish to thank my parents. They supported me and loved me. To them I dedicate this thesis,



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ABSTRACT

Electric Discharge Machining (EDM) is one of the most popular machining methods and manufactures dies and press tools because of its capacity to produced complicated shapes and machine very hard material. Intent of present study is to study the effect of different input parameters, namely, tool, current, concentration, pulse on time, pulse off time, powder on the output parameters MRR, TWR and SR. Hot die steel (H21) was is used as workpiece. Copper and tungsten-copper are used as tools. Effect of nickel and chromium powder is analysed in study. ANOVA is used to analyse the results. It has been observed that with addition of powder to dielectrics, there is increase in MRR by 20.34%, decrease in TWR by 45.58% and surface roughness reduces by 17.38%. It improves microhardness of material also.

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ABBREVIATION

ANOVA	Analysis of variance
DOF	Degree of freedom
EDM	Electric discharge machine
HDS	Hot die steel
MRR	Material removal rate
TWR	Tool wear rate
SR	Surface roughness
S/N	Signal to noise ratio

NOTATION

OA	Orthogonal array
A	Tool
B	Current
C	Concentration
D	Pulse on time
E	Pulse off time
F	Powder
Cu	Copper
W	Tungsten copper
CI	Confidence Interval
SS	Sum of square

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION TO NON-CONVENTIONAL PROCESSES

The many new materials and alloys that have been developed for specific uses process a very low machinability. Producing complicated geometries in such materials becomes extremely difficult with usual methods. Also, sometimes the combination of materials properties and the job dimensions is such that the use of the traditional machining properties becomes impossible. Examples of these types of jobs are machining a complicated turbine blade made of super alloys, and producing holes and slots in materials such as glass and semiconductors. At, times jobs becomes difficult to because of the dimensional complications. So, drilling of non circular hole or a micro hole becomes problematic, if the traditional processes are used. Apart from the situation cited, higher production rate and economic requirements may demand the use of non conventional machining processes.

To tackle such difficult jobs, unconventional machining processes are developed. These Operations use various types of energies to remove material. These machining processes are possibly categorized in four types i.e. . mechanical, electrochemical, chemical and thermal. These four categories are further classified as shown in Figure 1.1. In today's industry, super alloys and ceramic materials are extensively used in different industrial fields such as cutting tools, nozzles, turbine blades, internal combustion engines, and heat exchangers. Among these processes, electric discharge machining (EDM) has drawn as great deal of attention because of its broad industrial applications. The selection of processes is depend upon various factors like process capabilities, type of material for machining, physical parameters , shape and geometries and economics of process [1].

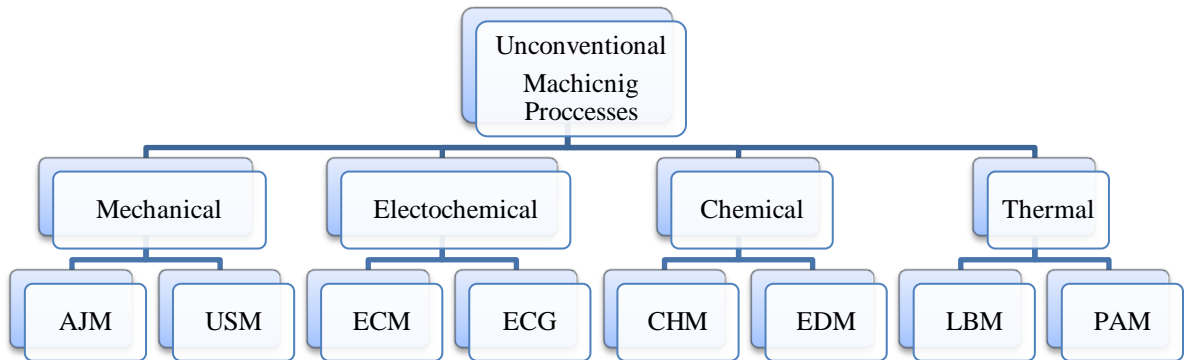


Figure 1.1 Classification of unconventional machining processes

The selection of processes is depend upon various factors like process capabilities, type of material for machining, physical parameters , shape and geometries and economics of process [1].

1.2 ELECTRIC DISCHARGE MACHINING

Electrical-discharge machining (EDM) is an unconventional, non contact machining process where metal removal is based on thermal principles. Electrical discharge machining (EDM) is a mature process in which melting and vaporization of the workpiece occurs through the action of high frequency electrical discharges/sparks generated between the tool and workpiece electrodes, which are separated by a small gap filled with a dielectric fluid. A heat affected zone is formed in the workpiece, the upper region comprising a recast layer of re-deposited/solidified melt material/ elements from the tool, work piece and dielectric fluid [2].

1.2.1 HISTORY

The history of EDM Machining Techniques goes as far back as the 1770s when it was discovered by an English Scientist. Electrical Discharge Machining was not fully taken advantage of until 1943 when Russian scientists learned how the erosive effects of the technique could be controlled and used for machining purposes [3].

The first EDM application was carried out by Mr. and Mrs. Lazarenko in the Technical Institute of Moscow during the Second World War. The first of the two important improvements, also carried out by these Soviet scientists, who make it feasible to elevate this electrical technique to the category of manufacturing process, was the RC relaxation circuit, which provided the first consistent dependable control of pulse times.

The second innovation consisted of adding a simple servo control circuit in order to find and hold a given gap automatically. In spite of these first trials and innovations, EDM technology got nearly unknown until the 1950s [2]. Commercially developed in the mid 1970s, wire EDM began to be a viable technique that helped shape the metal working industry we see today. In the mid 1980s, the EDM techniques were transferred to a machine tool. This migration made EDM more widely available and appealing over traditional machining processes [3]. The schematic diagram of EDM process is shown in Figure 1.2.

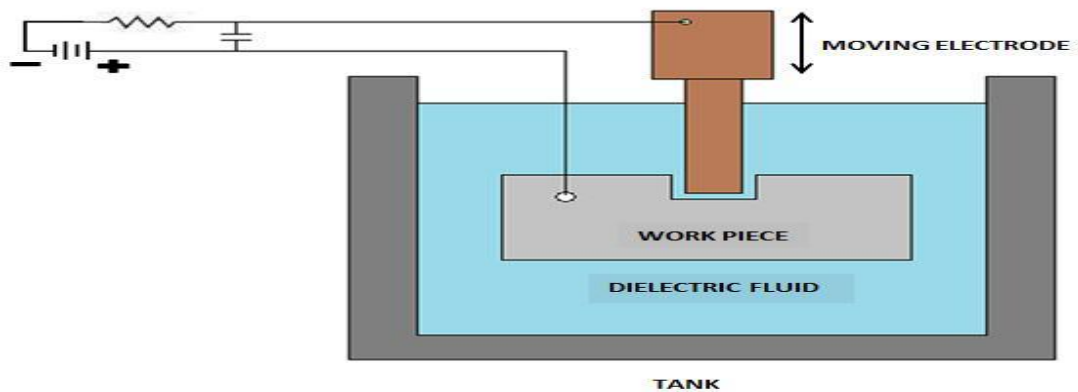


Figure 1.2 Schematic diagram of EDM process [3]

1.2.2 WORKING PRINCIPLE OF EDM

In EDM, a potential difference is applied between the tool and workpiece. Both the tool and the work material are to be conductors of electricity. The tool and the work material are immersed in a dielectric medium. Generally kerosene or deionized water is used as the dielectric medium. A gap is maintained between the tool and the workpiece.

Depending upon the applied potential difference and the gap between the tool and workpiece, an electric field would be established. Generally the tool is connected to the negative terminal of the generator and the workpiece is connected to positive terminal. As the electric field is established between the tool and the job, the free electrons on the tool are subjected to electrostatic forces. If the work function or the bonding energy of the electrons is less, electrons would be emitted from the tool (assuming it to be connected to the negative terminal). Such emission of electrons are called or termed as cold emission. The “cold emitted” electrons are then accelerated towards the job through the dielectric medium. As they gain velocity and energy, and start moving towards the job, there would be collisions between the electrons and dielectric molecules. Such collision may result in ionisation of the dielectric molecule depending upon the work function or ionisation energy of the dielectric molecule and the energy of the electron. Thus, as the electrons get accelerated, more positive ions and electrons would get generated due to collisions. This cyclic process would increase the concentration of electrons and ions in the dielectric medium between the tool and the job at the spark gap. The concentration would be so high that the matter existing in that channel could be characterized as “plasma”. The electrical resistance of such plasma channel would be very less. Thus all of a sudden, a large number of electrons will flow from the tool to the job and ions from the job to the tool. This is called avalanche motion of electrons. Such movement of electrons and ions can be visually seen as a spark. Thus the electrical energy is dissipated as the thermal energy of the spark.

The high speed electrons then impinge on the job and ions on the tool. The kinetic energy of the electrons and ions on impact with the surface of the job and tool respectively would be converted into thermal energy or heat flux. Such intense localized heat flux leads to extreme instantaneous confined rise in temperature which would be in excess of 10,000^o C. Such localized extreme rise in temperature leads to material removal. Material removal occurs due to instant vaporization of the material as well as due to melting. The molten metal is not removed completely but only partially. As the potential difference is withdrawn as shown in Figure 1.3, the plasma channel is no longer sustained. As the

plasma channel collapse, it generates pressure or shock waves, which evacuates the molten material forming a crater of removed material around the site of the spark.

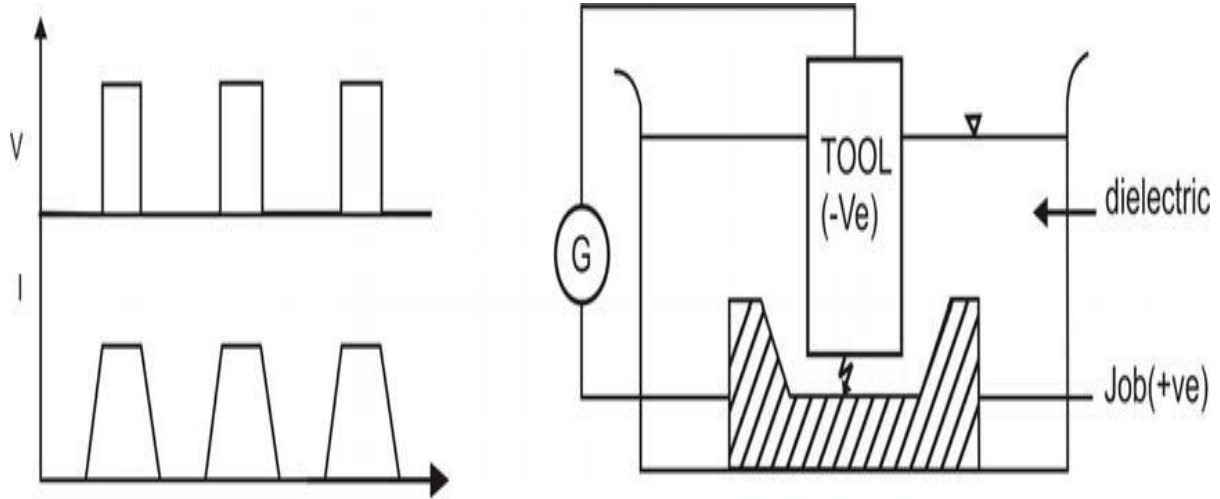


Figure 1.3 Schematic representation of the basic working principle of EDM process [2]

Thus to summaries, the material removal in EDM mainly occurs due to formation of shock waves as the plasma channel collapse owing to discontinuation of applied potential difference.

Generally the workpiece is made positive and the tool negative. Hence, the electrons strike the job leading to crater formation due to high temperature and melting and material removal. Similarly, the positive ions impinge on the tool leading to tool wear.

In EDM, the generator is used to apply voltage pulses between the tool and the job. A constant voltage is not applied. Only sparking is desired in EDM rather than arcing. Arcing leads to localized material removal at a particular point whereas sparks get distributed all over the tool surface leading to uniformly distributed material removal under the tool.

1.2.3 APPLICATIONS

1. The EDM process is most widely used by the mould-making tool and die industries, but is becoming a common method of making prototype and production parts, especially

in the aerospace, automobile and electronics industries in which production quantities are relatively low.

2. It is used to machine extremely hard materials that are difficult to machine like alloys, tool, steels, tungsten carbides etc.
3. Electro discharge machining (EDM) is used particularly when geometrically complex shape need to be incorporated into high-strength, electrically conductive materials [3].
4. Finishing EDM to produce parts for ultrahigh vacuum such as space environment using PMEDM.

1.2.4 LIMITATIONS

1. The major limitation is the slow rate of material removal.
2. High rate of electrode wear, surface and subsurface damage and creation of thin and brittle heat-affected zone.
3. EDM'd surfaces have defects such as micro cracks and pores that form because of the temperature gradient that is created near the surface [4].

To overcome these limitations, a number of efforts have been made to develop such EDM systems that have capability of high material removal rate (MRR), high accuracy and precision without making any major alterations in its basic principle. The techniques used in the past include (1) electrode rotating, (2) electrode orbiting — planetary motion to tool or workpiece (3) applications of ultrasonic vibrations and (4) suspension of foreign powders in the dielectric fluid. Among them, the mixing of a suitable material in powder form into the dielectric fluid is one of the latest advancement [5].

1.3 POWDERED MIXED ELECTRIC DISCHARGE MACHINING

In PMEDM, a suitable material (aluminum, chromium, copper, silicon carbide, etc.) in powder form is mixed into the dielectric fluid used in EDM. When a voltage of 80 – 320 Volts is applied between the tool electrode and the work piece placed close to each other, an electric field in the range of 105- 107 V/m is generated. The additive particles fill up the spark gap. It increases the spark gap. These high electric field energies powder

particles. These particles act as conductors. These conductive particles form chains at different places under sparking area, which bridges the gap between tool electrode and work piece material. Due to this bridging effect, the gap voltage and insulating strength of dielectric fluid reduces which facilitates easy short circuiting and hence early explosion in the gap between tool electrode and work piece material. Due to this, series discharges takes place within the gap. Due to increase in number of discharging per unit time, rapid sparking takes place that causes faster. At the same time the added powder particles enlarged the plasma channel. Due to this, electric density decreases and hence uniform distribution of sparking takes place. This leads to uniform erosion on work pieces which results in improvement in surface finish [6].

In this process, a suitable material in fine powder form is mixed into the dielectric fluid of EDM. The spark gap is filled up with additive particles. The added powder significantly affects the performance of EDM process. The electrically conductive powder reduces the insulating strength of the dielectric fluid and increases the spark gap distance between the tool electrode and workpiece. As a result, the process becomes more stable; thereby improving machining rate (MR) and surface finish [7].

Powder mixed electric discharge machining (PMEDM) is a recent innovation of EDM for enhancing its capabilities. PMEDM is very complex in nature and controlled by a large number of parameters, which are having impact on various responses [8].

1.3.1 MECHANISM OF POWDER MIXED EDM

PMEDM has a different machining mechanism from the conventional EDM. In this process, a suitable material in the powder form is mixed into the dielectric fluid either in the same tank or in a separate tank. For better circulation of the powder mixed dielectric, a stirring system is employed. For constant reuse of powder in the dielectric fluid, a modified circulation system (Fig. 1.4) is used. The experimental setup consists of a transparent bath like container, called machining tank. It is placed in the work tank of EDM and the machining is performed in this container. To hold the workpiece, a workpiece fixture assembly is placed in it. The machining tank is filled up with dielectric fluid (kerosene oil). To avoid particle settling, a stirring system was incorporated. A small dielectric circulation pump was installed for proper circulation of the powder mixed

dielectric fluid into the discharge gap. The pump and the stirrer assembly are placed in the same tank in which machining is performed. The distance between powder mixed dielectric suction point and nozzle outlet is kept as short as possible in order to ensure the complete suspension of powder in the discharge gap. Magnetic forces were used to separate the debris from the dielectric fluid. For this purpose, two permanent magnets are placed at the bottom of machining tank. The various powders that can be added into the dielectric fluid are aluminum, chromium, graphite, silicon, copper or silicon carbide, etc. The spark gap is filled up with powder particles. When a voltage of 80–320V is applied between the electrode and the workpiece facing each other with a gap of 25–50 μm , an electric field in the range of 105–107 V/m is created. The powder particles get energized and behave in a zigzag fashion (Fig. 1.5).

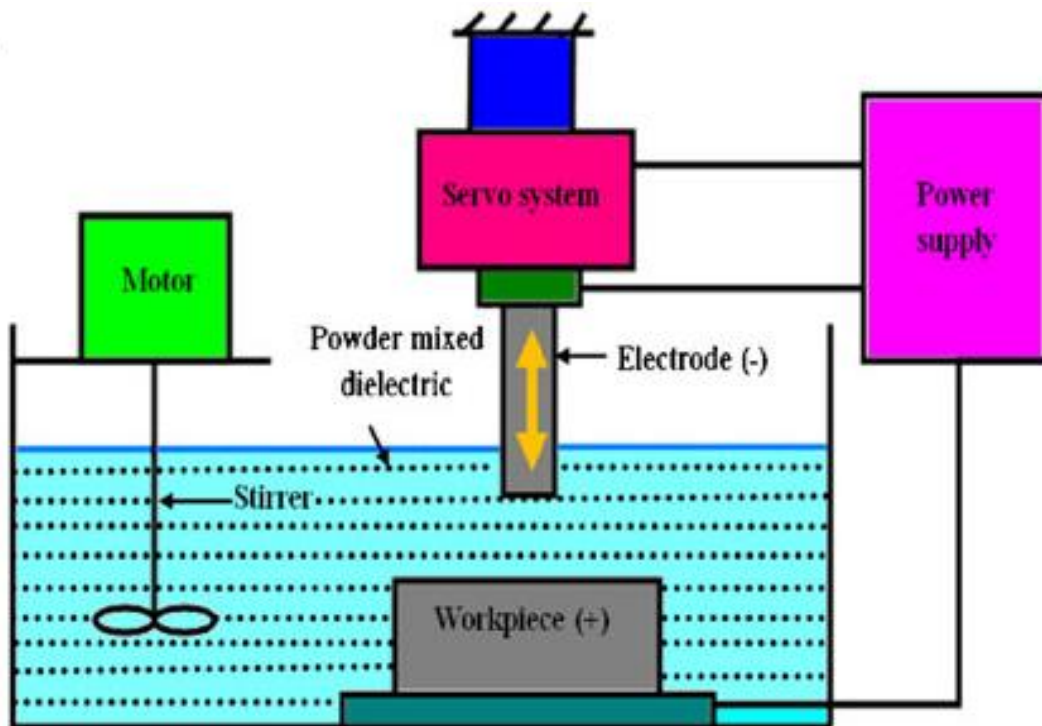


Figure 1.4 Schematic diagrams for PMEDM process with stirrer arrangement [14]

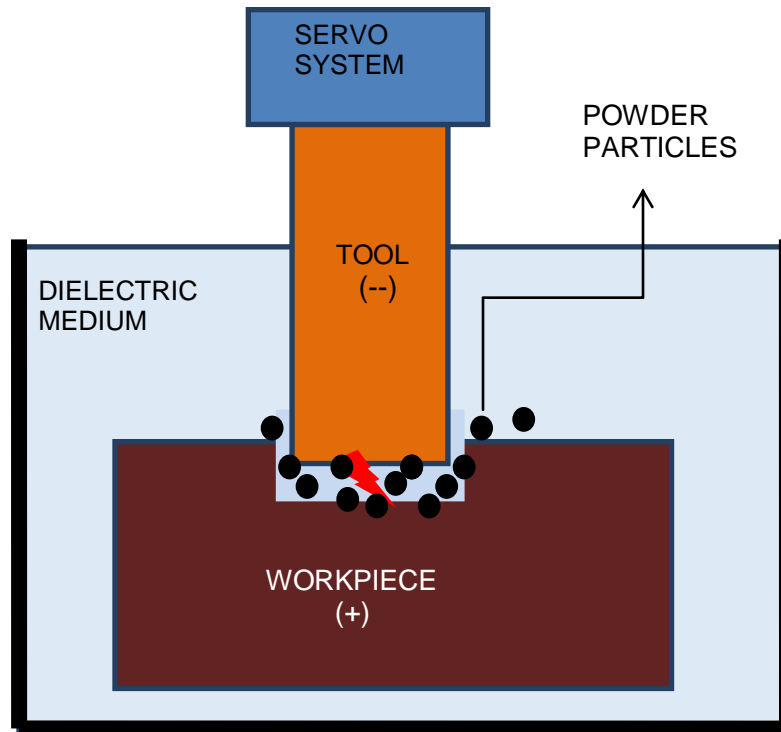


Figure 1.5 Mechanism of PMEDM [3]

These charged particles are accelerated by the electric field and act as conductors. The conductive particles promote breakdown in the gap and increase the spark gap between tool and the workpiece. Under the sparking area, the particles come close to each other and arrange themselves in the form of chain like structures between both the electrodes. The interlocking between the different powder particles occurs in the direction of flow of current. The chain formation helps in bridging the discharge gap between both the electrodes. Due to bridging effect, the insulating strength of the dielectric fluid decreases. The easy short circuit takes place, which causes early explosion in the gap. As a result, a ‘series discharge’ starts under the electrode area. The faster sparking within a discharge takes place causing faster erosion from the workpiece surface and hence the material removal rate (MRR) increases. At the same time, the added powder modifies the plasma channel. The plasma channel becomes enlarged and widened. The sparking is uniformly distributed among the powder particles, hence electric density of the spark decreases. Due to uniform distribution of sparking among the powder particles, shallow craters are produced on the workpiece surface. This results in improvement in surface finish [8].

1.4 PROCESS PARAMETERS

1.4.1 DISCHARGE CURRENT

Discharge voltage in the EDM is relative to spark gap and breakdown strength of the dielectric. Before current can flow the open circuit voltage increases until it create an ionization path through the dielectric. Once the current start to flow, voltage drops and stabilizes at working gap level. The preset voltage determines the width of spark gap between leading edges of the electrode and workpiece. Higher voltage increases, which improve flushing conditions and helps to stabilize [3].

1.4.2 PEAK CURRENT

This is the amount of power used in discharge machining, measured in units of ampere and is the most important parameters in EDM. During each on time pulse, current increases until it reaches a preset level, which is expressed as peak current [3].

1.4.3 PULSE ON TIME

Material removal is directly proportional to the amount of energy applied during this on-time. This energy is really controlled by the peak current and the length of the on-time. Extended on times gives more heat to workpiece, which means the recast layer will be larger and heat affected zone will be deeper. Hence, excessive on times can be counter-productive. When optimum on-time for each electrode –work material combination is exceeded, material removal rate starts to decreases.

1.4.4 PULSE OFF TIME

Pulse off time is the duration of time (μs) between the sparks (that is to say, on-time). This time allows the molten material to solidify and to be wash out of the arc gap. This parameter is to affect the speed and the stability of the cut. Thus, if the off-time is too short, it will cause sparks to be unstable [2].

1.4.5 POLARITY

In EDM machining, power sources can be divided into positive polarity machining (tool electrode: negative; workpiece: positive) and negative polarity machining (tool electrode: positive; work piece: negative) [2].

1.4.6 ARC GAP

Arc gap is the distance between the electrode and the part during the process of EDM. It may be called as spark gap [2].

1.4.7 DUTY CYCLE

Duty cycle is a percentage of the on-time relative to the total cycle time. This parameter is calculated by dividing the on-time by the total cycle time (on-time plus off-time) [2].

1.5 DIELECTRIC FLUID

In EDM, as has been discussed earlier, material removal mainly occurs due to thermal evaporation and melting. As thermal processing is required to be carried out in absence of oxygen so that the process can be controlled and oxidation avoided. Oxidation often leads to poor surface conductivity (electrical) of the work piece hindering further machining. Hence, dielectric fluid should provide an oxygen free machining environment. Further it should have enough strong dielectric resistance so that it does not breakdown electrically too easily but at the same time ionize when electrons collide with its molecule. Moreover, during sparking it should be thermally resistant as well.

The dielectric fluid has the following functions:

- (a) It helps in initiating discharge by serving as a conducting medium when ionised, and conveys the spark. It concentrates the energy to a very narrow region.
- (b) It helps in quenching the spark, cooling the work, tool electrode and enables arcing to be prevented.
- (c) It carries away the eroded metal along with it and acts as a coolant in quenching the sparks.

The electrode wear rate, metal removal rate and other operation characteristics are also influenced by the dielectric fluid.

The dielectric generally fluid used are transformer oil, silicon oil, EDM oil, kerosene (paraffin oil) and de-ionized water are used as dielectric fluid in EDM. Tap water cannot be used as it ionizes too early and thus breakdown due to presence of salts as impurities

occur. Dielectric medium is generally flushed around the spark zone. It is also applied through the tool to achieve efficient removal of molten material. In this experiment using the Commercial grade EDM oil (specific gravity= 0.763, freezing point= 94°C) was used as dielectric fluid are used it is using as coolant and medium of workpiece and tool during the process of erosion.

1.5.1 TYPES OF FLUSHING

It is basic requirement of dielectric that it should maintain it should maintain its dielectric strength during whole operation. There is no problem at start of EDM ,but after discharge the debris are produced in the gap ,reduce the dielectric strength ,Which cause unwanted discharge which can damage to both toll and work pieces. Hence, effective flushing is required to remove unwanted debris [10]. In EDM following types of flushing achieved.

1.5.1.1 SUCTION FLUSHING

In this, dielectric may be sucked through either the workpiece or the electrode. This technique is employed to avoid tapering effect due to sparking between machining debris and side walls of electrode.

1.5.1.2 INJECTION FLUSHING

In this technique, dielectric is fed through either the workpiece or tool which is pre drilled to accommodate the flow. With the injection method tapering of components arises due to lateral discharge action occurring as result of particles being flushed up the side of the electrode.

1.5.1.3 SIDE FLUSHING

When flushing hole cannot be drilled either in the workpiece or the tool, side flushing is employed. If there is need of flushing of entire working area, special precautions have to taken for pumping of dielectrics.

1.6 ELECTRODE MATERIAL

The selection of electrode material depends on the

- (1) Material removal rate
- (2) Wear ratio
- (3) Ease of shaping the electrode

The most commonly used electrode materials are brass, copper, graphite, Al, copper tungsten alloys and silver tungsten alloys [1].

Thus the basic characteristics of electrode materials are:

1. High electrical conductivity – electrons are cold emitted more easily and there is less bulk electrical heating.
2. High thermal conductivity – for the same heat load, the local temperature rise would be less due to faster heat conducted to the bulk of the tool and thus less tool wear.
3. Higher density – for the same heat load and same tool wear by weight there would be less volume removal or tool wear and thus less dimensional loss or inaccuracy.
4. High melting point – high melting point leads to fewer tools wear due to less tool material melting for the same heat load.
5. Easy manufacturability.

2.1 INTRODUCTION

Large amount of work has been done in different field of electric discharge machining and powder mixed EDM. This chapter mainly covers literature review of powder mixed electric discharge machining, which was collected from research papers and other information sources. In this report literature survey classified mainly in two categories:

1. Powdered mixed EDM using other powders
2. Powdered mixed EDM using Nickel and Chromium powders

2.1.1 POWDERED MIXED EDM USING OTHER POWDERS

Batish et al. [11] had optimized the parameters of of powder mixed electric discharge machining using dummy treated experimental design with analytical hierarchy process (AHP). In the experiment, three types of steels high carbon high chromium, EN-31 and hot die steels were used as workpieces. Effect of seven different parameters had been investigated to measure output responses material removal rate (MRR), tool wear rate (TWR), and surface roughness (SR). Specially designed Taguchi orthogonal array was designed accommodate factors with varying number of levels. The process conditions that affected the three responses were identified and optimized together using AHP for high carbon high chromium (HCHCr), EN31 and hot die steel (HDS) workpiece material. Three factors current, electrode material, and pulse on time were found to be the most significant factors affecting MRR. TWR reduced with addition of powder with tungsten powder causing the lowest TWR. SR improved with addition of powder, which is due to more uniform distribution of sparking that causes a more uniformly distributed crater.

Bhattacharya et al. [12] had investigated the effect of electric discharge machining (EDM) process parameters and powder mixed in dielectric on surface properties of three die steel work materials; namely High Carbon High Chromium (HCHCr), EN 31 and Hot

Die Steel (HDS). Current emerged as the most significant factor affecting the microhardness along with powder mixed in the dielectric and electrode material. Amongst the two electrode materials, copper-tungsten along with tungsten powder had the best microhardness. The mechanism of material deposition from the suspended powder and/or tool electrode was reported. Selected samples were analyzed for X-ray Diffraction (XRD) followed by microstructure analysis using a Scanning Electron Microscope (SEM). The results showed significant material transfer from the electrode as well as powder either in free form or in compound form. It was concluded that surface modification of die steels can be done by incorporating simple modifications in the EDM set-up resulting in higher microhardness and superior wear resistance of the machined surface.

Batish et al. [13] investigated mechanism of material deposition from powder, electrode and dielectric for surface modification of H11 and H13 die steels in EDM process. There were four different powder that were decided to use in the present study for two workpiece materials, graphite and aluminum (Al) powder were selected for H11 and H13 in Kerosene and refined mineral oil dielectrics. Microhardness measurements at deposited and non-deposited region showed that there was a significant proportion of increase in microhardness in the deposited region. As high as 37% increase in microhardness was noticed at deposited region for H11 workpiece and 56% increase for H13 workpiece.

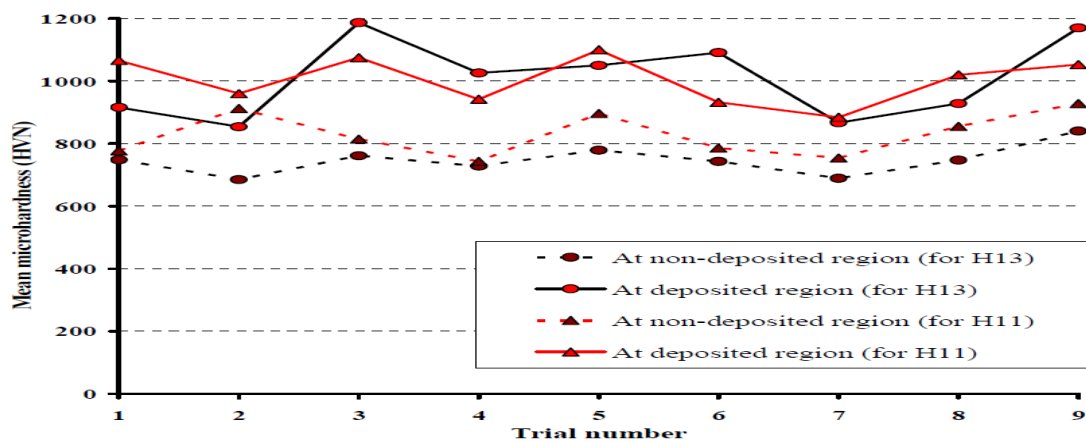


Figure 2.1 Improvement in microhardness for H13 and H11 die steels after machining with PMEDM [13]

It was found that transfer of material from electrode wherein deposition of W on the machined surface resulted a significant increase in microhardness. Use of W-Cu electrode also resulted increase in microhardness which proved the material transfer from electrode during EDM. This phenomenon was evidence that at higher current setting, breakdown of dielectric and possible deposition of material from dielectric and significant increase in microhardness could be expected due to the carbide formation under such conditions. The micrograph also showed some carbon rich phase due to material movement from electrode helped in formation of tungsten carbide and/or iron carbide on the machined surface with a significant increase in microhardness.

Batish et al. [14] investigated the effect of process parameters and mechanism of material deposition in powder mixed electric discharge machining (PMEDM) on surface properties of EN31, H11, and High Carbon High Chromium (HCHCr) die steel materials. Current, powder, and interaction between workpiece and electrode affected the microhardness significantly. Graphite powder was found to be more suitable compared to aluminum in improving the microhardness of all three materials. Copper electrode was found best for EN31 and H11 die steel, whereas tungsten-copper electrode was better suited for HCHCr steel to achieve higher microhardness. Selected samples were analyzed for X-ray diffraction (XRD) followed by microstructure analysis using a scanning electron microscope (SEM). The results showed significant material transfer from the electrode as well as powder, either in free form and/or in compound form. For maximizing the microhardness of the machined surface, optimum parametric settings were identified for the three materials.

Bhattacharya et al. [15] optimized parameter settings for rough and finish machining of die steels in powder-mixed EDM. The experiments were conducted on die steels EN31, H11, and high carbon high chromium (HCHCr) die steel materials in a powder-mixed electric discharge machining process. The effect of different input parameters, namely, current, electrode material, dielectric medium, pulse on time, pulse off time, and powder mixed in dielectric and some of their interactions on the MRR, TWR, and SR of three different die steel materials had been studied. The effect of these parameters on output responses had been analyzed using Analysis of Variance (ANOVA) to establish additive

equations for each response and for each material. The optimal parametric setting using additive equations had been developed for both rough and finished machining.

Puertas et al. [16] focused on aspects related to surface quality and dimensional precision, which were one of the most important parameters from the point of view of selecting the optimum conditions of processes, as well as economical aspects. The parameters were optimized to improve surface quality in manufacturing processing by using mathematical model which would allow selecting optimum manufacturing conditions. The fact of having to employ high current values to obtain a better surface roughness in this experiment might be due to a better arc stability causing a more uniform production of sparks and a narrow variation interval of the surface roughness parameters.

Gurule et al.[17] reported effect of tool rotation on material removal rate during powder mixed electric discharge machining of die steel. It was found that addition of aluminum powder to dielectric media enhanced the MRR; added powder improves the breakdown characteristics of dielectric. Flushing had shown least effect on MRR.

Kansal et al. [18] discussed detailed summary of research results reported in the area of powder mixed EDM. It could be concluded from this review that PMEDM holds a bright promise in application of EDM, particularly with regard to process productivity and surface quality of workpiece. As such, extensive study was required to understand mechanics of machining and other aspects of PMEDM. Different types of technologies and research trends in Powder mixed EDM were discussed.

Pecas et al. [19] had studied the influence of the dielectric flow rate and powder concentration in the surface morphology in electrical discharge machining with powder-mixed dielectric (PMD-EDM). The powder concentration, the flushing flow and the electrode area were varied during the tests in order to assess their influence over the process technological performance, measured through the craters' average diameter and depth, the white-layer thickness, the final surface roughness and the type of discharges occurred. Results of a set of tests designed to assess the influence of the silicon powder concentration in the surface morphology were presented. The rise of the silicon concentration from 0 to 2 g/l promotes a decrease of the surface roughness. However, for

a higher concentration the surface roughness values increased directly with the silicon concentration. One can also observed that for the 10 and 20 g/l samples the surface roughness heterogeneity increased dramatically. The dielectric flow rate was varied from 0.5 to 2.5 l/min for the several electrode areas between 100 to 6400 mm².

Singh et al. [20] had examined to optimized parameters of Abrasive Powder Mixed EDM of Aluminum Matrix Composites(AMCs).They used Gray Relational Analysis(GRA) for evaluating the results of experiments. It was observed that pulse on time has the strongest effect on the multiple performance characteristics among the other machining parameters. The increase in the abrasive powder concentration also helped to bridge the gap between the tool electrode and the work material, thus increasing the rate of MRR. APM-EDM of AA6061-based MMCs reinforced with 20% alumina (Al₂O₃) particulates with SiC mixed in the dielectric fluid, the optimal level setting of eight process parameters were Aspect ratio 0.7179, Pulse current 0.6898, Pulse on current 0.7248, Duty cycle 0.6983, Gap voltage 0.6944, Tool electrode lift time0.7062, Abrasive powder concentration 0.6972, and Abrasive particle size 0.6944 for maximizing MRR and minimizing tool wear and SR according to the results of response table and main effects plot.

Sharma et al. [21] had been made to study the effect of aluminum powder on the machining performance of conventional EDM with reverse polarity. The output parameters TWR, MRR, WR and SR are investigated by varying concentration and particle size of Al powder in Powder mixed EDM. It was found that MRR and TWR increased with increasing the concentration of Al powder. It was also found that WR an SR were decreased with increasing the concentration of Al powder.

Chow et al. [22] studied the performance of micro slit –EDM with addition of SiC powder in water and pure water. They had taken input variables were polarity and pulse on time and measured output parameters were MRR and EWR. It was revealed that MRR increased with NP (negative polarity) machining pulse duration.EWR had shown opposite trend to MRR. Results indicated that the addition of SiC powder would increase working fluid electrical conductivity, enlarge the electrode and workpiece gap, and also extrude debris easily, therefore increasing the material removal rate.

Singh S. et al. [23] examined the effect on performance of electric discharge machining of die steel by varying the concentration and composition of powder mixed in dielectric medium. The variations of two machining performance outputs such as MRR and TWR had been planned to be studied with regard to varying machining parameters peak current, pulse on time, pulse off time, gap and spark time. With the addition of the powders in the dielectric, material removal rate had been increased to a great extent and the tool wear rate had been reduced.

Kolahan et al. [24] proposed mathematical model, using regression method, to model and analysis the effects of machining parameters on the machining characteristics in the PMEDM process. Important process outputs, including metal removal rate and electrode wear rate had been investigated by effects of four machining parameters (grain size of aluminum powder, concentration of the powder, discharge current and pulse on time). To model the machining process, different regression functions had been fitted to the experimental data. Then, using analysis of variance (ANOVA), the best and most fitted set of models were identified. In addition to influence of individual machining parameters, the interactions between these parameters were also investigated. Finally, a genetic algorithm procedure had been employed to optimize the process parameters for any set of desired outputs.

Kung et al. [25] made their study by taking four processing input parameters: discharge current, pulse on time, grain size and concentration of aluminum powder particles for machinability evaluation of MRR and TWR for cobalt bonded tungsten carbides. The response surface methodology (RSM) has been used to plan and analyze the experiments. The experimental plan adopts the face-centered central composite design (CCD). This study highlights the development of mathematical models for investigating the influence of processing parameters on performance characteristics.

Abbas et al. [26] studied Hydrocarbon based dielectric usually kerosene was widely used by the Malaysian industries. The information was collected by interviews and surveys. Estimation of kerosene as waste was provided. Research finding shows that, an estimated amount of 4393 liters of dielectric will be disposed by an average EDM manufacturer in

Malaysia, which could develop alarming pollution condition. Suggestions on alternative machining method such as machining with distilled water or dry EDM were given.

Wu et al. [27] examined the influence of surfactant on the characteristics of EDM process on SKD61 .It was observed that agglomeration of debris near electrodes, when dielectric was used without surfactant. With addition of addition of Span 20 (30 g/L) surfactant to kerosene, the material removal rate is increased by about 40%. Debris was equally dispersed in dielectric to improve the effects of carbon accumulation and reduce the unstable concentrated discharge. Surface roughness was not affected, since the material removal rate was great. Conductivity of kerosene was improved by addition of surfactant, which helped to improve the machining efficiency.

Janmanee et al. [28] studied modification of tungsten carbides with the help of electric discharge machining using a titanium powder suspension in dielectric medium. The current and duty cycles were varied to change in the titanium coating layer thickness. An analysis of the chemical composition using energy dispersive spectroscopy (EDS) revealed that a titanium coating layer was formed enhancing the hardness of the titanium surface to 1750 HV. The surface was evaluated using scanning electron microscopy (SEM).It was found that small number of micro cracks were found on the surface since the micro cracks were filled and substituted by titanium powder and carbon (a hydrocarbon) that decomposed from the dielectric ,which helped to improve micro hardness of workpiece material(Tungsten carbide).

Kansal et al.[29] optimized the process parameters of powder mixed electrical discharge machining (PMEDM) by using response surface methodology. Material removal rate and surface roughness were analyzed by input variables pulse on time, duty cycle, peak current and concentration of the silicon powder added into the dielectric fluid of EDM. Peak current and concentration strongly interacted with each other. Experimentation revealed that MRR increased with the increased in the concentration of the silicon powder. Surface roughness was also reduced with increase concentration of silicon powder.

Wong et al. [30] presented analysis of the influence of the material powder type in the EDM polished surfaces. Number of experiments were performed on various types of steels with different types of powder concentrations (Al, graphite, crushed glass, Si, SiC). Mirror type surface finish could be produced by specific combination powder mixed dielectric and workpieces. The effect of pulse duration and polarity also examined, Negative polarity gave best result to get mirror- finish.

Wu et al. [31] tried to improve the surface finish on SKD steel using electric discharge machining with aluminum and surfactant added dielectric. The influence of surfactant on the surface roughness of the working piece was discussed. Optimal machining parameters for EDM were also proposed. Taguchi method was used to optimize the process parameters to improve surface finish. The experiments were conducted without powder additives, with Al powder and with Al powder & surfactant. The kerosene with Al powder and surfactant had shown best results. Surfactant helped to avoid the agglomeration of Al powder near tool electrode. The effect of polarity of workpiece was also studied. The negative polarity of the workpiece had an inferior surface roughness than that under positive polarity in EDM.

Jahan et al. [32] investigated the feasibility of achieving fine surface finish in the micro-EDM of WC–Co using graphite Nano-powder additives in dielectric oil, as this powder had been reported to provide improved surface finish in different studies. In this regard, a comparative evaluation of powder-mixed sinking and milling micro-EDM had been carried out on the basis of spark gap, MRR, EWR and overall the surface topography. It was observed that the spark gap increased significantly with the increase of powder concentration for graphite-mixed dielectric. During the micro-EDM, the presence of conductive or semi-conductive powders in the working gap could drastically lower the breakdown strength of dielectric, which eventually results in a higher spark gap

Velmurugan et al. [33] investigated the effect of parameters like Current, Pulse on time, Voltage and Flushing pressure on material removal rate, tool wear rate as well as surface roughness (SR) on the machining of hybrid Al6061 metal matrix composites reinforced with 10% SiC and 4% graphite particles. Composite was fabricated using stir casting process. A central composite rotatable design was selected for conducting experiments.

Mathematical models were developed using the MINITAB R14 software. The method of least squares technique was used to calculate the regression coefficients and Analysis of Variance (ANOVA) technique was used to check the significance of the models developed. Scanning Electron Microscope (SEM) analysis was done to study the surface characteristics of the machined specimens and correlated with the models developed.

Garg et al. [34] discussed review of research work in sinking EDM and wire EDM on metal matrix composites. Greater hardness and reinforcement makes it difficult to machine using traditional techniques, which had impeded the development of MMCs. The use of traditional machinery to machine hard composite materials causes serious tool wear due to the abrasive nature of reinforcement. These materials could be machined by many non-traditional methods like water jet and laser cutting but these processes are limited to linear cutting only. The paper discussed the future trend of research work in the same area. It was found that lots of work had been reported on the aluminum matrix composites (AMCs).

Kumar et al. [35] investigated surface modification of three die steel materials to by EDM method with tungsten powder mixed in the dielectric medium. Designs of experiments were carried out Taguchi experimental design technique. Peak current, pulse on-time and pulse off time were taken as variable factors and micro-hardness of the machined surface was taken as the response parameter. High temperature between electrode and workpiece broke hydrocarbon dielectric, which contributed carbon to plasma channel. Carbon combined with tungsten powder to form tungsten carbide on surface of workpiece, which improved micro hardness work piece material (OHNS, HC-HCr and H13 die steels).

Zhao et al. [36] discussed application of powder mixed EDM in rough machining .Powdered mixed EDM was mainly used for finish working. In this paper number of experiments were performed to improve machining efficiency and surface roughness by selecting proper process parameters .The results were also compared with traditional EDM(without powder) .It was found that powder mixed EDM showed better results than traditional EDM.

Rozenek et al. [37] reported investigations of EDM using powder suspended working fluid instead pure dielectric. The EDM characteristics obtained using hydrocarbon dielectric (kerosene) and mixture deionized water with abrasive powder had been compared. The relationship between surface roughness parameters, material removal rate and operating parameters of EDM had been determined for different kind of powder and its concentration in kerosene/water. The investigation results shown that there were chances for replacing the conventional dielectric with water and that would imply considerable economic and ecology advantages.

2.1.2 POWDERED MIXED EDM USING NICKEL AND CHROMIUM POWDER

Li et al. [38] presented a study of the effect of titanium carbide TiC on the performance of sintered copper-based materials as electrical discharge machining EDM. The aim of this study was to provide a preliminary evaluation of EDM electrodes fabricated by laser-based sintering using rapid prototyping technology. Six batches of titanium carbide with content from 5% to 45% were fabricated by mixing, ball milling, pressing, and liquid phase sintering with copper-tungsten Cu-W and copper Cu, respectively. The performance of the newly formed material was compared with commercial electrodes. The densification of TiC-Cu-W system was improved by the addition of nickel Ni, as Ni showed good solubility in both Cu and W. The distribution of particle size becomes narrow as the proportion of TiC was increased. A uniform dispersion of small TiC particles in the Cu-W system and a narrow particle size distribution provided the possibility of obtaining dense electrodes. With increasing TiC, the relative density first increased and then decreased, whereas the electrical resistivity first decreased and then increased. EDM electrodes, with the addition of TiC, show good performance in surface finishing. This was an important characteristic as RP-sintered EDM electrodes are expected to be used as finishing electrodes. The surface roughness of most specimens is less than those machined using commercial electrodes. Electrodes with 15% TiC show the highest relative density, lowest electrical resistivity, and good EDM performance, i.e. . lowest tool wear ratio TWR and highest material removal rate MRR at low current, and the best surface finish not only at low current, but also at high current.

Uno et al. [39] studied surface modification of EDM surface with powder mixed fluid. The EDMed surface with metal powder mixed fluid has smaller surface roughness and higher resistance to corrosion because of the diffusion of electrode and/or powder materials into the machined surface. In this study, a new surface modification technique was proposed to obtain high surface wear resistance using EDM with powder mixed fluid. Firstly, a coating application of nickel layer on aluminum bronze for plastic molds and shell mold cores was discussed. Secondly, formation of a hard titanium carbide layer on alloy tool steel was explained using carbon powder mixed fluid with titanium electrodes.

Ojha et al. [40] investigated modeling of PMEDM process with Chromium Powder Suspended Dielectric. Material removal rate (MRR) and tool wear rate (TWR) was studied on the powder mixed electrical discharge machining (PMEDM) of EN-8 steel has been carried out. Response surface methodology (RSM) had been used to plan and analyze the experiments. Peak current, pulse on time, diameter of electrode and concentration of chromium powder added into dielectric fluid of EDM were chosen as process parameters to study the PMEDM performance in terms of MRR and TWR. Experiments had been performed on newly designed experimental setup developed in laboratory. Most important parameters affecting selected performance measures had been identified and optimum process conditions had been found. Also recommended optimal conditions had been verified by conducting confirmation experiments.

Ojha et al. [41] had studied the effect chromium powder using triangular shape electrodes. Parametric optimization for material removal rate (MRR) and tool wear rate (TWR) study on the powder mixed electrical discharge machining (PMEDM) of EN-8 steel was carried out. Response surface methodology (RSM) had been used to plan and analyze the experiments. Average current, duty cycle, angle of electrode and concentration of chromium powder added into dielectric fluid of EDM were chosen as process parameters to study the PMEDM performance in terms of MRR and TWR. Experiments had been performed on newly designed experimental setup developed in laboratory. Most important parameters affecting selected performance measures have been identified and effects of their variations had been observed.

Tzeng et al. [42] presented the effects of various powder characteristics on the efficiency of electro discharge machining (EDM) SKD-11. The additives examined include aluminum (Al), chromium (Cr), copper (Cu), and silicon carbide (SiC) powders that had significant differences in their thermo physical properties. The machining mechanism with the addition of the foreign particles, the tool wear rate (TWR), and the material removal rate (MRR) had been investigated. It was found experimentally that the particle concentration, the particle size, the particle density, the electrical resistivity, and the thermal conductivity of powders were important characteristics that significantly affected the machining performance in the EDM process. Proper addition of powders to the dielectric fluid increased the MRR and, thus, decreased the TWR. Under the same particle concentration experiments, the smallest suspended particle size led to the greatest MRR and, thus, the lowest TWR. Of the additives investigated, chromium powder produced the greatest MRR and the lowest TWR, whereas the process without foreign particles had the converse effects. The addition of copper powder to the dielectric fluid was found to make almost no difference to the pure kerosene EDM system.

2.2 SUMMARY OF LITERATURE REVIEW

Lot of work has been done in measuring of process parameters like surface roughness (SR), material removal rate (MRR), tool wear rate (TWR) in powder EDM. These output process parameters are evaluated by input variables like discharge current, pulse on time, pulse off time, duty cycle, powder concentration. Many researchers [6], [10], [24], [30] reported work on powder mixed EDM by using silicon powder mixed dielectric fluid and measured process parameters such as SR, TWR and MRR. Silicon powder enhanced MRR and SR [6], [24]. Some researchers [22], [26] used surfactant to reduce agglomeration of powder particles in dielectric fluid. [3], [19] and [30] used aluminum powder to process parameters MRR, SR and TWR. Some researchers [1], [5], [12] and [32] had made their study by using graphite powder in dielectric fluid. Silicon carbides were also used by some researchers [1], [9], [30]. Effect of titanium powder was also investigated by [3]. Process parameters were evaluated in many research papers. Material removal rate increased with increasing the concentration powder in dielectric fluid [6],[11],[12], [17], [23] and [24]. This was because of the added additive causes bridging

effect between both the electrodes, facilitates the dispersion of discharge into several increments and hence increased the MRR [35]. Discharge current significantly affected MRR. MRR increased with increasing discharge current had reported in [6], [7], [22], [24], [35]. This could be due to an increase in discharge energy with increase in discharge current, which improves the rate of melting and evaporation. Higher powder concentration also contributed to the improvement in surface smoothness had been reported in [3], [5], [10], [14], [24] and [33]. Because plasma channel became enlarged and widened. The electric density decreased; hence sparking was uniformly distributed among the powder particles. As a result, even and uniform surfaces were produced [24]. It was observed that the tool wear rate was increased with the addition of graphite powder [23] in the dielectric and using reverse polarity [30]. But some researchers [34], [18], [19] said that tool wear rate decreased with addition of powder particles in dielectric. The reason for this was that the powder particles come in the path of ions moving towards electrode surface. It reduced the momentum of striking ions with electrode surface. The ions with low energy strike the electrode and hence erode less material from electrode.

2.3 GAPS IN LITRATURE REVIEW

The field of surface modification using EDM process is still in at experimental stage. A number of research studies have been carried out and feasibility of the process is well established. From the literature review, it is observed that no work has been carried out on surface modification using nickel and chromium powder in EDM oil dielectric fluid along copper and tungsten-copper electrode. The surface modification in EDM oil as dielectric medium is missing. No work has been reported on H21 die steel and tungsten-copper electrode in EDM oil. All the aspects will be addressed in this research work.

PILOT EXPERIMENT & DESIGN OF STUDY

3.1 INTRODUCTION

The chapter discusses objectives of proposed work, explains the methodology to be adopted and gives the details of experimental work to be carried out in a phased manner. The objective of the work, various issues to be solved to meet the objective, details of material, equipment etc. have also been provided.

3.2 OBJECTIVE OF PROPOSED WORK

The present research work is aimed at studying the:

- H21 steel is known as one of the difficult to machine materials using conventional machining processes because of its high hardness.
- In the present study, circular shaped workpieces were machined with an EDM with a view to investigate its cutting performance on each workpiece under varying cutting conditions.
- Significant factors which are affecting the process for optimization.

3.3 PILOT EXPERIMENTATION

The effect of various inputs i.e. current ,pulse on , pulse off , type of tool, type of powder were investigated through pilot experimentation. Two responses were selected for pilot experimentation namely material removal rate (MRR) and tool wear rate (TWR). The assignment of factors was carried out using statistical software MINITAB. All the factors were varied at three levels excepts type of powder. Type of powder factor was assigned with two levels. The degree of freedom required for experiment was calculated to be 11. Thus; the orthogonal array that could be used should have degree of freedom greater than 11. L₁₈ which could accommodate combination of 2 levels and 3 levels was used for

conduction of experiments. After the conduct of 18 trials, the mean values for MRR and TWR are tabulated in for analysis of results. Analysis of variance (ANOVA) was used for analyze the results.

Table 3.1 L₁₈ Taguchi design along with results for powder mixed EDM process during pilot experimentation

Trial No.	Current (A)	Powder	Concentration (g/L)	Pulse On (μs)	Pulse off (μs)	Tool	MRR (mm ³ /min)	TWR (mm ³ /min)
1	3	Ni	3	20	38	Br	2.73	3.36
2	3	Ni	6	50	57	WC	4.92	0.11
3	3	Ni	9	100	85	Cu	5.13	0.22
4	5	Ni	3	20	57	WC	5.69	0.43
5	5	Ni	6	50	85	Cu	6.38	0.57
6	5	Ni	9	100	38	Br	7.65	5.64
7	7	Ni	3	50	38	Cu	9.01	0.69
8	7	Ni	6	100	57	Br	12.09	8.58
9	7	Ni	9	20	85	WC	9.48	0.57
10	3	Cr	3	100	85	WC	6.57	0.22
11	3	Cr	6	20	38	Cu	5.88	0.33
12	3	Cr	9	50	57	Br	4.36	5.87
13	5	Cr	3	50	85	Br	4.56	6.05
14	5	Cr	6	100	38	WC	7.88	0.27
15	5	Cr	9	20	57	Cu	8.40	0.34
16	7	Cr	3	100	57	Cu	13.66	0.73
17	7	Cr	6	20	85	Br	7.38	7.94
18	7	Cr	9	50	38	WC	10.35	0.51

The relationship of MRR with current, concentration, pulse on and pulse off using brass, copper tungsten-copper electrodes in powder mixed dielectric is shown in the figure 3.1.

It was observed that at low current, MRR is low but increases sharply with increased current. ANOVA for MRR is given in table 3.1. The current was to be significant factors affecting MRR. The MRR increased with increase in pulse on time and decreased with pulse off time. The powder concentration has also significant. Further, it was observed that MRR increased with copper tool. It had low value on brass tool.

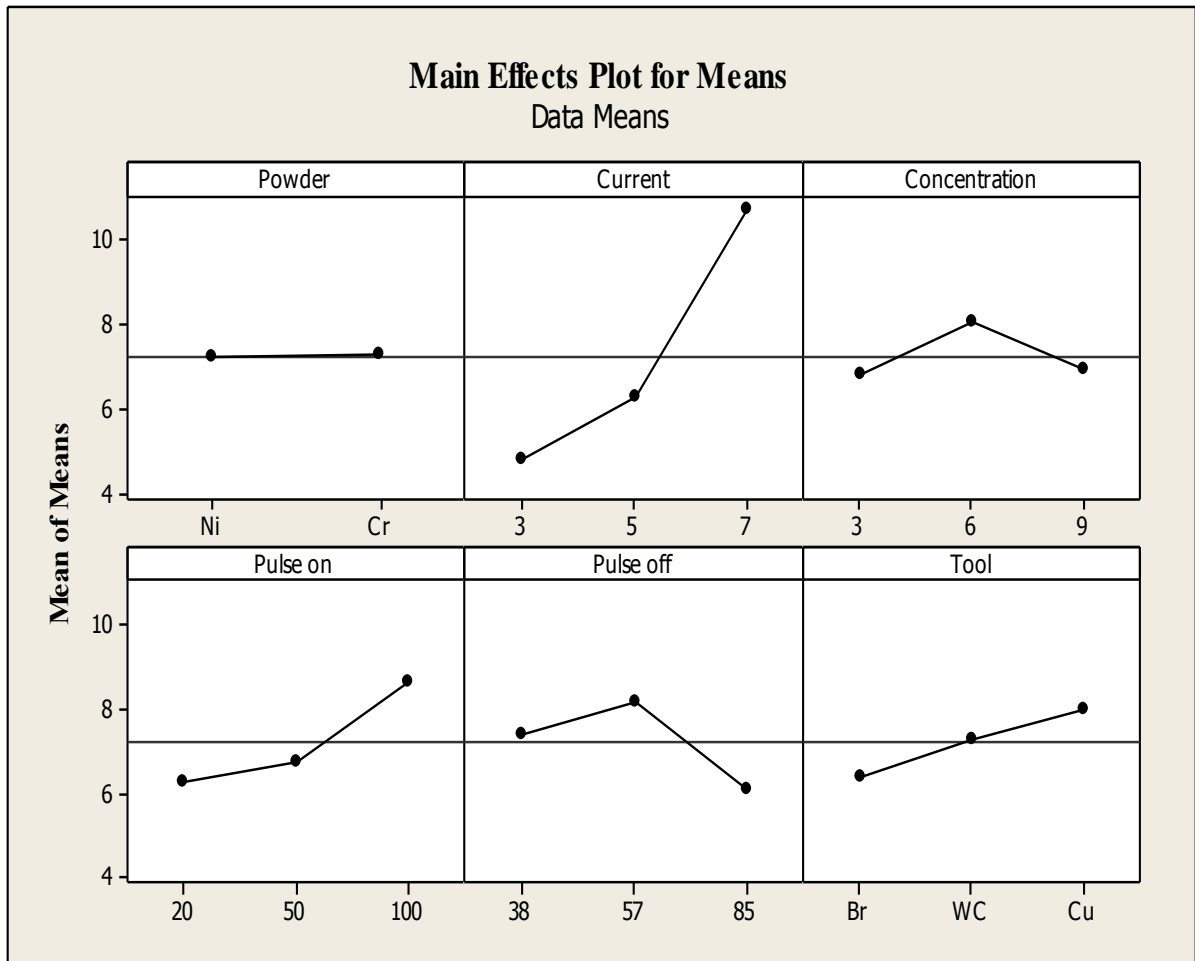


Figure 3.1 Main effects for MRR during pilot experimentation

The relationship of TWR with current, pulse on time, pulse off time during machining with brass, copper and copper-tungsten electrodes in powder mixed dielectric is shown in figure. The electrode material was found to be most significant factors affecting TWR. With copper showed least TWR while brass tool had maximum TWR. Also increase in current caused high TWR, while all other factors had insignificant effect on TWR.

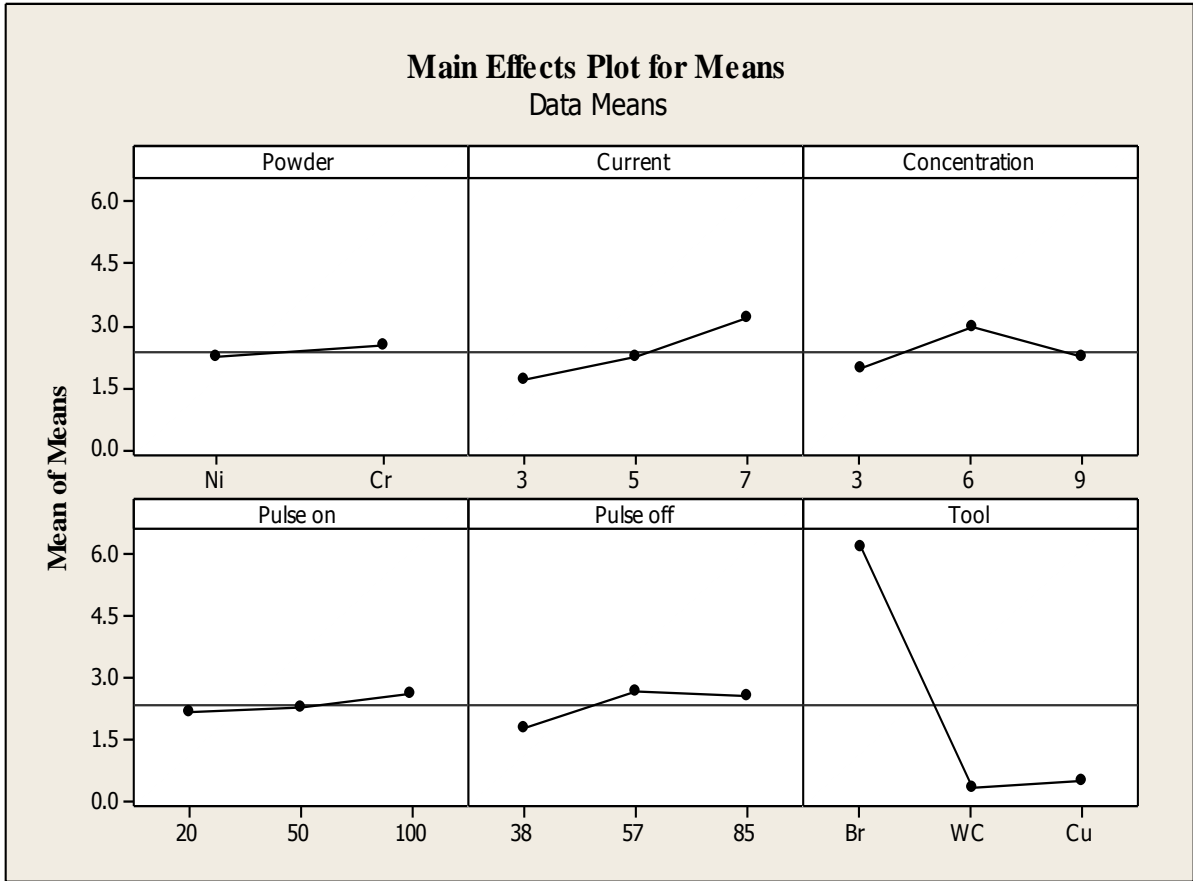


Figure 3.2 Main effect of for TWR during pilot experimentation

3.4 METHODOLOGY

In methodology, main objective of research work is to evaluate the response of input parameters such as discharge current, pulse on time, and pulse off time and powder concentration on output parameters such as material removal rate, tool wear rate and surface roughness. Experiments will be carried out on Electric Discharge Machine model T-3822 of Victory Electromech available at Thapar University in Machine Tool lab. Process parameters are discussed as follows. Experiments will be designed by using Taguchi method so that effect of all parameters will be studied with minimum number of experiments. The results will be analysed using analysis of variance (ANOVA). Evaluation of effects of process parameters such as discharge current, pulse on time, pulse off time and powder concentration on material removal rate, tool wear rate and surface roughness will be studied.

3.5 PROCEDURE OF EXPERIMENTAL DESIGN

The whole procedure of Taguchi method is under:

1. Establishment of objective functions.
2. Selection of factors.
3. Identification of uncontrollable factors and test condition.
4. Selection of number of levels for controllable factors.
5. Calculation of degree of freedom.
6. Select the appropriate orthogonal array (OA).
7. Assignment of factors.
8. Execution of experiment according to trial condition.
9. Analyze Results.

3.6 SELECTION OF FACTORS

The determination of which factors to investigate depends on responses of interest. The factors affects the responses were identified using cause and effect analysis, brainstorming and pilot experimentation. The lists of factors studied with their levels are shown in Tables 3.2.

Table 3.2 Factors interested and their levels

FACTORS	LEVELS		
	Level 1	Level 2	Level 3
Powder, A	Nickel	Chromium	
Tool, B	Copper	Tungsten-Copper	
Current(A),C	3	5	7
Pulse on time (μ s),D	20	50	100
Pulse off time (μ s),E	38	57	85
Concentration, F	3	5	7

3.7 EXPERRIMENT DESIGN

The minimum DOF required in the experiment re the sum of all the degree of freedom of factors. In the present experiment setup, there are five 3-level factors and one tool is 2 level factors. The number DOF for factors A,C,D,E and F are two and for factor B is one .Total DOF for the experiment is 11.The orthogonal array(OA) to be used should have more than 1 DOF. The most suitable orthogonal array that can be used for the experiment is L₁₈.Which has 17 DOF assigned to its various column. The additional six DOF used to measure random error.

Table 3.3 Degree of Freedom

Factor	A	B	C	D	E	F	Total
Degree of freedom	2	1	2	2	2	2	11

3.7.1 ORTHOGONAL ARRAY

In mathematics, in the area of combinatorial designs, an orthogonal array is a "table" (array) whose entries come from a fixed finite set of symbols (typically, {1,2,...,n}), arranged in such a way that there is an integer t so that for every selection of t columns of the table, all ordered t-tuples of the symbols, formed by taking the entries in each row restricted to these columns, appear the same number of times. The number t is called the strength of the orthogonal array.To select an appropriate orthogonal array for experiments, the total degrees of freedom must be computed. The degrees of freedom are defined as the number of comparisons between process parameters that must be made to determine which level is better and, specifically, how much better it is. For example, a two-level process parameter counts for one degree of freedom. The degrees of freedom associated with interaction between two process parameters are given by the product of the degrees of freedom for the two process parameters.

3.7.2 TAGUCHI DESIGN

A Taguchi design, or an orthogonal array, is a method of designing experiments that usually requires only a fraction of the full factorial combinations. An orthogonal array means the design is balanced so that factor levels are weighted equally. Because of this, each factor can be evaluated independently of all the other factors, so the effect of one factor does not influence the estimation of another factor.

In robust parameter design, you first choose control factors and their levels and choose an orthogonal array appropriate for these control factors. The control factors comprise the inner array. At the same time, you determine a set of noise factors, along with an experimental design for this set of factors. The noise factors comprise the outer array. The experiment is carried out by running the complete set of noise factor settings at each combination of control factor settings (at each run). The response data from each run of the noise factors in the outer array are usually aligned in a row, next to the factors settings for that run of the control factors in the inner array.

3.7.3 CHOOSING TAGUCHI DESIGN

Before you use Minitab, you need to determine which Taguchi design is most appropriate for your experiment. In Taguchi designs, responses are measured at selected combinations of the control factor levels. Each combination of control factor levels is called a run and each measure an observation. The Taguchi design provides the specifications for each experimental test run. A Taguchi design, also known as an orthogonal array, is a fractional factorial matrix that ensures a balanced comparison of levels of any factor. In a Taguchi design analysis, each factor can be evaluated independently of all other factors.

When choosing a design you need to

1. Identify the number of control factors that are of interest
2. Identify the number of levels for each factor
3. Determine the number of runs you can perform
4. Determine the impact of other considerations on your choice of design.

Table 3.4 L₁₈ Experimental Design

Trial No.	Tool	Current (A)	Concentration (g/l)	Pulse on (μs)	Pulse off (μs)	Powder
1	Cu	3	3	20	38	Ni
2	Cu	3	5	50	57	Cr
3	Cu	3	7	100	85	Mix
4	Cu	5	3	20	57	Cr
5	Cu	5	5	50	85	Mix
6	Cu	5	7	100	38	Ni
7	Cu	7	3	50	38	Mix
8	Cu	7	5	100	57	Ni
9	Cu	7	7	20	85	Cr
10	W	3	3	100	85	Cr
11	W	3	5	20	38	Mix
12	W	3	7	50	57	Ni
13	W	5	3	50	85	Ni
14	W	5	5	100	38	Cr
15	W	5	7	20	57	Mix
16	W	7	3	100	57	Mix
17	W	7	5	20	85	Ni
18	W	7	7	50	38	Cr

3.8 EXPERIMENT SETUP

The experiments had been conducted on EDM model T-3822 of VICTORY ELECTROMECH available at Thapar University, Patiala in Machine Tool Lab as shown in figure 3.1. An experimental setup was developed to run the research tests for the two different powder conditions. Many input parameters can be varied in EDM process like discharge voltage, pulse on time ,pulse off time ,polarity, peak current, electrode gap and type of flushing, each factor has its own effect on output parameters such as tool wear rate(TWR), material removal rate(MRR), Surface Roughness and microhardness of machined surface. The range of parameters varied for experiment work was selected on basis of pilot experiment. The input parameters, which were kept constant during experimentation, are given in table 3.5.

Table 3.5 Constant parameters

S.No.	Parameters	Value
1	Open Circuit Voltage	135+/- 5
2	Polarity	Positive
3	Machining Time	10 minutes
4	Spark Energy	Low

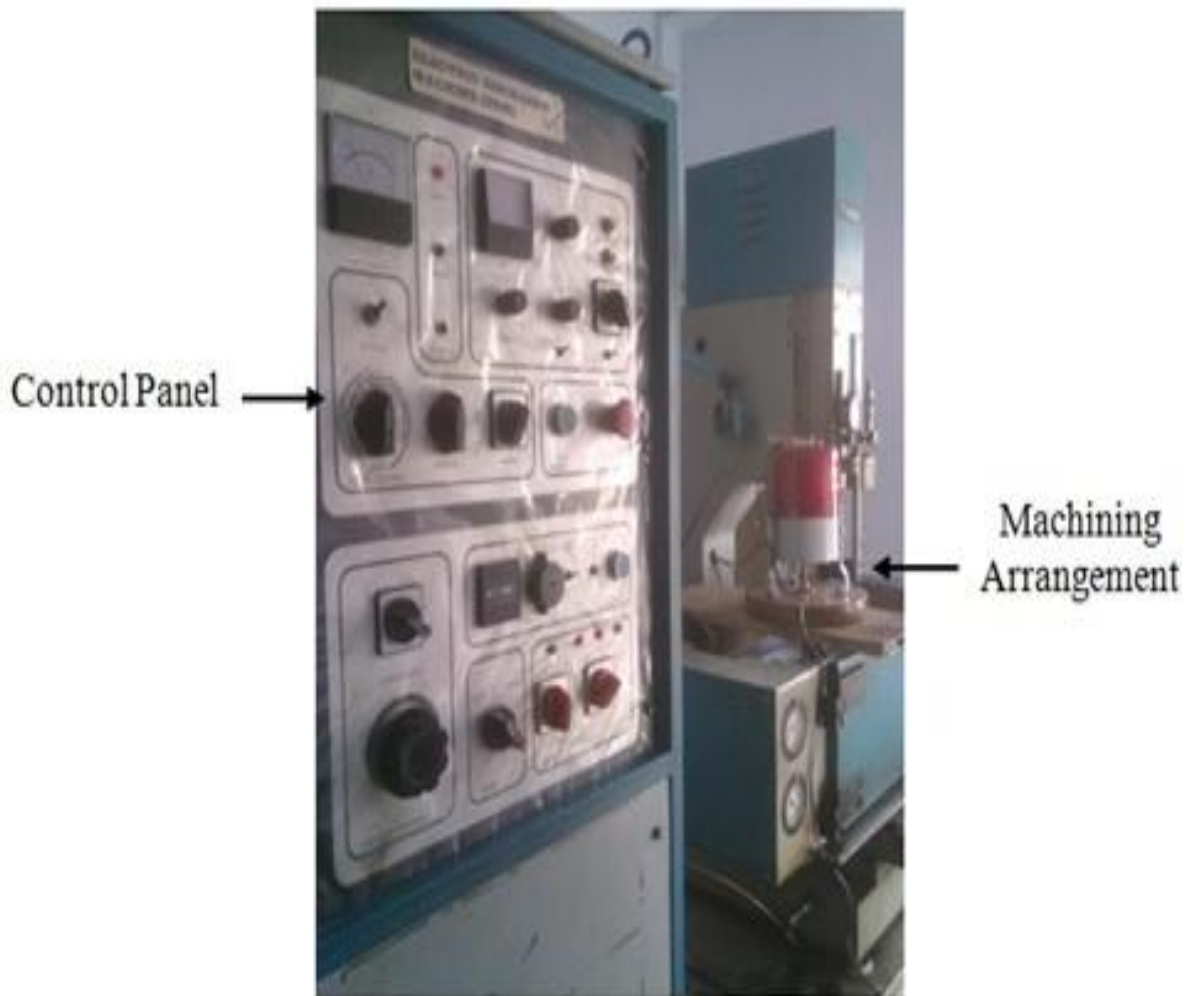


Figure 3.1 EDM machine (Courtesy by: MT Lab, Thapar University, Patiala)

3.8.1 MEASURING AND TEST EQUIPMENT

MRR and TWR were measured using weighing machine. Microhardness and Surface roughness tests were conducted on all samples. The detail of all equipment used in experiment study is given below:

3.8.1.1 SURFACE ROUGHNESS TESTER

Surface Roughness was measured using Perthometer model M4Pi of Maher, Germany available in Metrology Lab at Thapar University, Patiala. The equipment uses stylus method of measurement has profile resolution of 12 nm and measure roughness up to 100 μ m. A tracing length of 4.8mm was used for analysis. Surface roughness of each sample was measured at two different positions namely centre and side of each machined samples.



Figure 3.3 Surface hardness Tester (Courtesy by: Meterology Lab, Thapar University, Patiala)

3.8.1.2 MICROHARDNESS TESTER

Micro hardness was measured on a interfaced Micro Hardness Tester (model MVH-2) available at Thapar University, Patiala. The microhardness is dependent on diameter of

indentation on the samples. The indents formed in pyramid shaped indenter were measured Quantiment software using loads of 1Kg for 20 seconds.



Figure 3.3 MicrohardnessTester (Courtesy by: Meteorology Lab, Thapar University, Patiala)

3.9 ANALYSIS OF VARIANCE

ANOVA is a statistical technique which can guess some important conclusions based on analysis of the experimental data. The method is very useful for revealing the level of significance of influence of factor(s) or interaction of factors on a particular response. It separates the total variability of the response (sum of squared deviations about the grand mean) into contributions rendered by each of the parameter/ factor and the error. Thus

$$SS_T = SS_F + SS_E$$

$$\text{Where } SS_T = \sum_{j=1}^P (\gamma_j - \gamma_m)^2$$

Where SS_T = Total sum of squared deviations about the mean.

γ_j = Mean response for j^{th} experiment.

γ_m = Grand mean of the response.

SS_F = Sum of squared deviations due to each factor.

SS_E = Sum of squared deviations due to error.

In the ANOVA table mean square deviation is defined as:

MS = Mean Square

$$MS = \frac{SS \text{ (Sum of squared division)}}{DOF \text{ (Degree of Freedom)}}$$

F-value of Fisher's F ratio (Variance ratio) is defined as:

$$F = \frac{MS \text{ for a term}}{MS \text{ for the error term}}$$

3.9.1 SIGNAL-TO-NOISE RATIO

In the Taguchi method, there are three categories of performance characteristic in the analysis of the signal-to-noise ratio, that is, the lower-the-better, the higher-the-better, and the nominal the better. The change in quality characteristic of a product under investigation in response to a factor introduced in the experimental design is the 'signal' of the desired effect. The effect of the external factors (uncontrollable factors) on the outcome of quality characteristic is termed as 'noise'. The objective of any experiment is to achieve the best possible S/N ratio.

Finding a correct objective function to maximize in an engineering design problem is very important. Depending upon the type of response, the following three types of S/N ratios are employed in practice:

- **Higher the Better**

$$(S/N)_{HB} = -10 \log (MSD_{HB})$$

$$\text{Where } MSD_{HB} = \frac{1}{R} \sum_{j=1}^R \left(\frac{1}{y_j^2} \right)$$

MSD_{HB} = Mean Square Deviation for higher-the-better response

- **Lower the Better**

$$(S/N)_{LB} = -10 \log (MSD_{LB})$$

$$\text{Where } MSD_{LB} = \frac{1}{R} \sum_{j=1}^R (y_j^2)$$

MSD_{LB} = Mean Square Deviation for Lower-the-better response

- **Nominal the Best**

$$(S/N)_{NB} = -10 \log (MSD_{NB})$$

$$\text{Where } MSD_{NB} = \frac{1}{R} \sum_{j=1}^R (y_j - y_0)^2$$

MSD_{NB} = Mean Square Deviation for Nominal the best response

3.10 TEST RESULTS FOR WORKPIECE AND ELECTRODE MATERIAL

The workpiece material Hot Die Steel (H21) and two electrodes material Copper and Tungsten-Copper were used. Before, start of experimentation, the chemical composition of workpiece was measured on optical emission spectrometer DV-6. The percentage composition of workpiece and electrode materials is provided in table 3.6 and table 3.7.

Table 3.6 Chemical composition of workpiece material (Courtesy by: Meteorology Lab, Thapar University, Patiala)

Workpiece	Fe	C	Si	Mn	Cr	Mo	V	W
	Composition (%)							
H21	86.55	0.35	0.30	0.40	2.80	0.60	0.40	9.0

Table 3.7 Chemical composition of tool material (Courtesy by: CSIR-CSIO, Chandigarh)

Electrode	W	Cu	Si	Ni	Z	Ti	Pb
	Composition (%)						
Tungsten-copper	80.94	18.49		0.126	0.040	0.015	0.027
Copper		99.80		0.043	0.08	0.029	0.045

Table 3.8 Microhardness of workpiece

Material	Microhardness(hvn)
Hot die steel(H21)	88.83

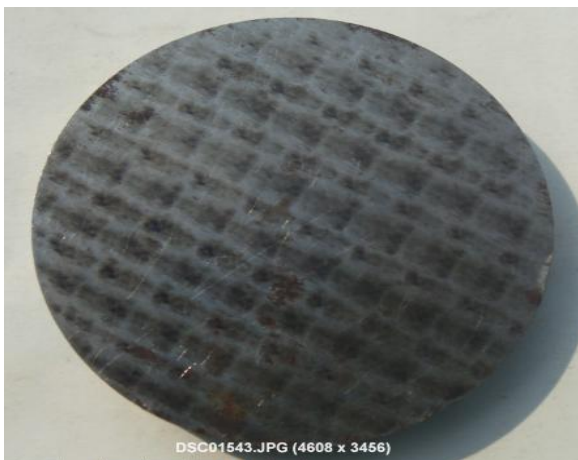


Figure 3.8 (A) Workpiece material



Figure 3.8 (B) Tool material

CHAPTER 4

RESULTS AND ANALYSIS OF MRR

4.1 INTRODUCTION

The effect of parameters i.e. . tool, current, concentration, pulse on, pulse off, and powder were evaluated using ANOVA. The confidence interval of 95% has been used for analysis. One repetition for 18 trials was completed so as to measure signal to noise ratio (S/N Ratio).

4.2 RESULTS FOR MRR

The results for MRR for each of 18 treatment conditions with repetition are given in Table 4.1. MRR of each sample was calculated from weight difference of workpieces before and after the trial:

$$MRR = \frac{W_i - W_f}{\rho \times t} \times 1000 \text{ mm}^3 / \text{min}$$

Where

W_i = Initial weight of workpiece materials (gms)

W_f = Final weight of workpiece materials (gms)

t = Time period of trials in minutes (min)

ρ = Density of workpiece in gms/cc

Table 4.1: Results for MRR

Trial No.	Tool	Current (A)	Concentration (g/l)	Pulse on (μ s)	Pulse off (μ s)	Powder	MRR(mm ³ /min)		Mean MRR (mm ³ /min)	S/N Ratio
							1	2		
1	Cu	3	3	20	38	Ni	3.29	3.13	3.21	10.12
2	Cu	3	5	50	57	Cr	4.36	4.45	4.40	12.87
3	Cu	3	7	100	85	Mix	5.97	6.27	6.12	15.72
4	Cu	5	3	20	57	Cr	5.81	5.85	5.83	15.31
5	Cu	5	5	50	85	Mix	7.25	7.16	7.20	17.15
6	Cu	5	7	100	38	Ni	11.17	10.99	11.08	20.88
7	Cu	7	3	50	38	Mix	8.37	8.55	8.46	18.54
8	Cu	7	5	100	57	Ni	15.28	15.53	15.40	23.75
9	Cu	7	7	20	85	Cr	9.01	8.85	8.93	19.01
10	W	3	3	100	85	Cr	5.19	5.25	5.22	14.35
11	W	3	5	20	38	Mix	3.93	4.01	3.97	11.97
12	W	3	7	50	57	Ni	3.99	4.25	4.12	12.28
13	W	5	3	50	85	Ni	7.25	7.13	7.19	17.13
14	W	5	5	100	38	Cr	9.27	9.43	9.35	19.41
15	W	5	7	20	57	Mix	6.27	6.19	6.23	15.88
16	W	7	3	100	57	Mix	12.79	12.71	12.75	22.11
17	W	7	5	20	85	Ni	8.39	8.69	8.54	18.62
18	W	7	7	50	38	Cr	9.46	9.62	9.54	19.59

4.3 ANALYSIS OF VARIANCE FOR MRR

The results were analyzed using ANOVA for identifying the significance factors affecting the performance measures. The analysis of variance for mean MRR 95% confidence interval is given in table 4.2. The variation of data for each was F-tested to find significance of each. The principle of F-test is that larger the F- value for particular parameters, the greater the effect on performance characteristics due to change in that process parameter. ANOVA tables shows that current (F value 70.29), pulse on time (F value 32.07), powder (F value 2.26) are factor that are significantly affect MRR. All other

factor namely, tool, pulse off time and concentration were found to be insignificant. Table 4.3 shows the ranks of various factors in the terms of their relative significance. Current has highest rank, significantly highest contribution to MRR.

Table 4.2 Analysis of variance of MRR

Source	DF	SS	SS'	F	P
Tool(A)	1	0.775	0.775	0.97	0.363
Current(B)	2	111.775	55.8875	70.29	0.001
Concentration(C)	2	3.226	1.6130	2.03	0.212
Pulse on(D)	2	50.992	25.4958	32.07	0.002
Pulse off(E)	2	2.568	1.2838	1.61	0.0275
Powder(F)	2	3.588	1.7939	2.26	
Residual Error	6	4.771	0.7939		
Total	17	177.694			

Table 4.3 Response table for MRR

Level	Tool	Current	Concentration	Pulse on	Pulse off	Powder
1	7.849	4.507	7.110	6.118	7.602	8.857
2	7.434	7.814	8.146	6.820	8.123	7.21
3		10.604	7.670	9.987	7.201	7.456
Delta	0.415	6.097	1.036	3.869	0.923	1.045

Figure 4.1, effect of various factors i.e. current, pulse on time, pulse off time, concentration of powder, tool and powder are shown in material removal rate. It is clear from graph that as current increases, MRR goes on increasing. This could be due to an increase in discharge energy with increase in discharge current, which improves the rate of melting and evaporation. Same is effect of pulse on time. With increase in pulse on time more thermal energy enters into workpiece and more metal turns into liquid form, resulting in increasing MRR. An increase in pulse-off time decreases the MRR. This may

be because machining time decrease with an increase in pulse-off time .As seen in graph, MRR increases with concentration. Because,the increase in the abrasive powder concentration also helps to bridge the gap between the tool electrode and the work material, thus increasing the rate of MRR. But after level 2(5g/l) to level 3 (5g/l), MRR decreases, due to higher abrasive particle concentration with higher particle size display a discharge interference phenomenon. Nickel powder gives highest MRR among other powder (Chromium and Mix).

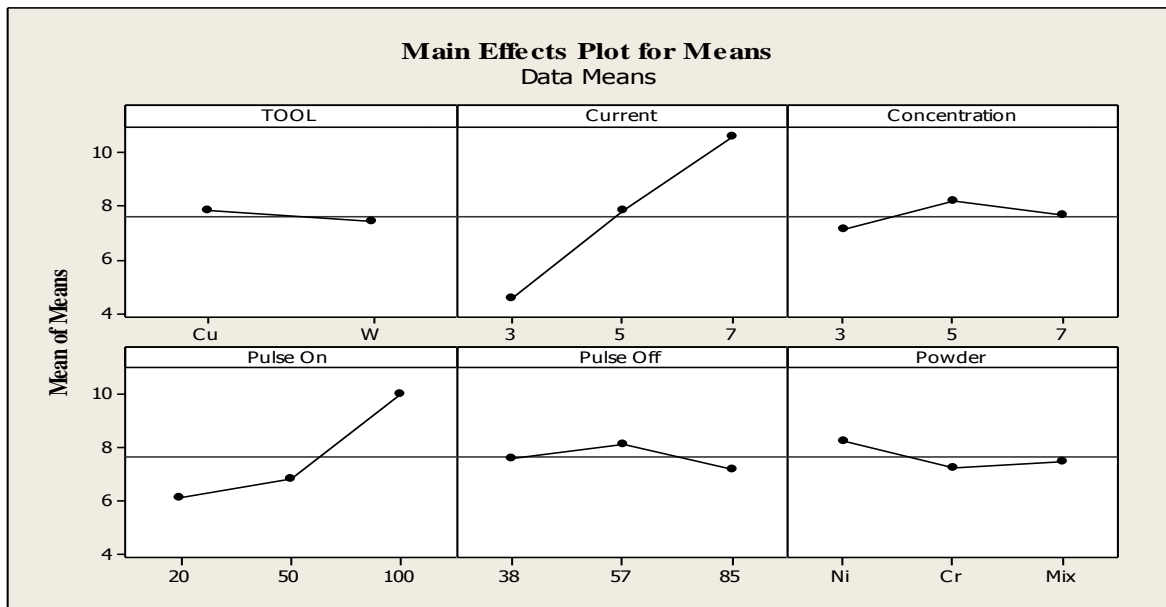


Figure 4.1 Main effects plot for Means for MRR

4.4 RESULTS FOR S/N RATIO OF MRR

The S/N ratio consolidates several repetitions into one value and is indication of amount of variation present. The S/N ratios have been calculated to identify the major contributing factors that cause variation in MRR. MRR is considered “Higher is better” which is given by:

- **Higher the Better**

$$(S/N)_{HB} = -10 \log (\text{MSD}_{HB})$$

$$\text{Where } \text{MSD}_{HB} = \frac{1}{R} \sum_{j=1}^R \left(\frac{1}{y_j^2} \right)$$

MSD_{HB} = Mean Square Deviation for higher-the-better response

Table 4.4 Response table for S/N ratio of MRR

Level	Tool	Current	Concentration	Pulse on	Pulse off	Powder
1	17.04	12.89	16.26	15.16	16.76	17.13
2	16.82	17.63	17.30	16.26	17.04	16.76
3		20.27	17.23	19.37	17.00	16.90
Delta	0.22		1.04	4.22	0.28	0.37
	6	1	3	2	5	4

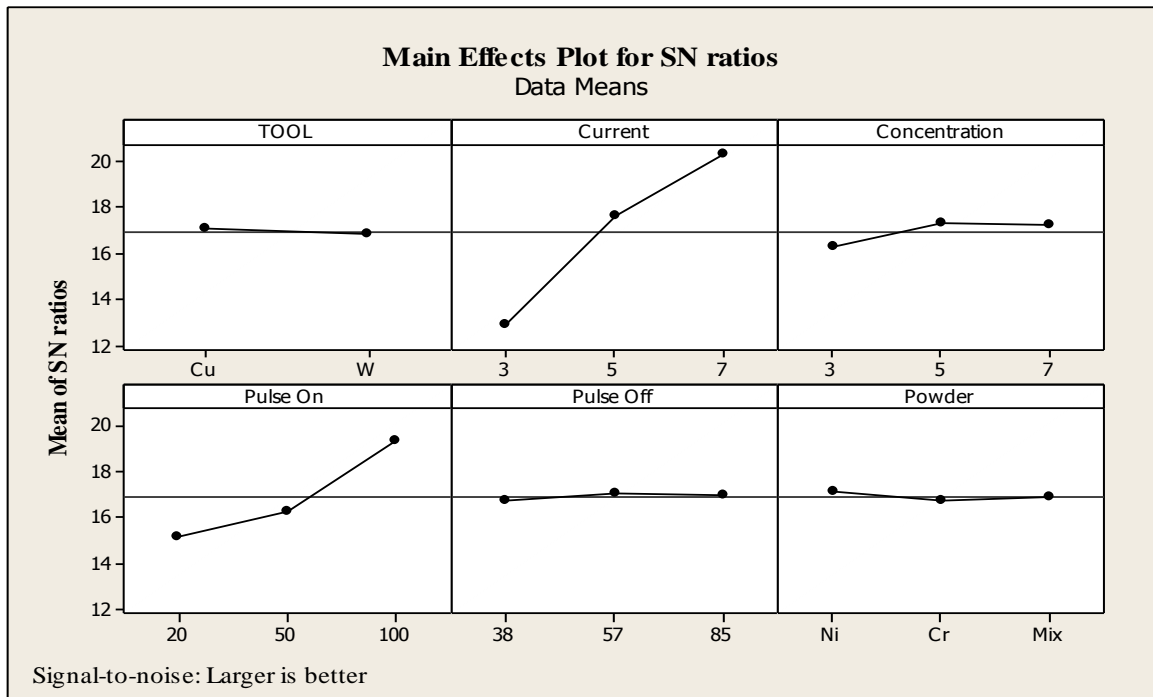


Figure 4.2 Main effect plot of S/N ratio for MRR

4.5 OPTIMAL DESIGN FOR MRR

In this experiment analysis, the main effect plot as shown in figure 4.1 was used to estimate the mean MRR. From the table, it is concluded that when H21 workpiece was machined at current (7 A) and pulse on (100µs). In S/N ratio highest MRR was observed when workpiece was machined at current 7A. And Pulse on time 100µs. Significant factors are shown in table 4.5.

Table 4.5 Significant Factor for MRR

Factor	Affecting Mean		Affecting Variation	
	Contribution	Best Level	Contribution	Best Level
Tool, A	Insignificant	-	Insignificant	-
Current, B	Significant	Level 3 (7 A)	Significant	Level 3(7 A)
Concentration, C	Insignificant	-	Insignificant	-
Pulse on , D	Significant	Level 3 (100 µs)	Significant	Level 3 (100 µs)
Pulse off, E	Insignificant	-	Insignificant	-
Powder, F	Insignificant	-	Insignificant	-

In experiment analysis the MRR is higher average response is better characteristic. Depending on characteristics has chosen to obtain satisfactory results. After conducting the experiment, the optimum treatment conditions are selected to determine one of experiment.

Mean value of MRR

$$\mu_{B_3D_3} = B_3 + D_3 - T$$

$$= 9.98 + 10.60 - 7.64 = 12.94 \text{ mm}^3/\text{min}$$

Confidence Interval around the estimated value

$$CI_1 = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{\eta_{eff}}}$$

Where F_{α, v_1, v_2} = F ratio

α = risk (0.05) confidence = $1 - \alpha$

v_1 = degree of freedom for mean which is always = 1

v_2 = (Total degree's of freedom) - (degree's of freedom of significant factors)

V_e = $(SS_{total} - SS_{significant\ factors}) / (\text{total DOF} - \text{DOF of significant factors})$

$$\eta_{eff} = \frac{N}{1 + dof_{A,c}} = \frac{18}{1 + 2 + 2} = 3.6$$

$$CI_1 = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{\eta_{eff}}} = \sqrt{\frac{4.67 \times 1.14}{3.6}} = 1.21$$

So confidence interval around MRR is given by $12.95 \pm 1.21 \text{ mm}^3/\text{min}$

It has been observed from experimental data that the powder is not acting as a significant parameter. Therefore, to see the effect powder addition on MRR, we had conducted the experiments using optimal parameters with and without powder. It was observed that there was 20.34% increase in MRR with addition of Nickel powder. Following table 4.6 showed outcomes of experiment.

Table 4.6 Conformational experiment results

S.No.	Tool	Current (A)	Concentration (g/l)	Pulse on (μ s)	Pulse off(μ s)	Powder	MRR Without Powder (mm^3/min)	MRR With Powder (mm^3/min)
1	Cu	7	5	100	20	Ni	11.08	13.91

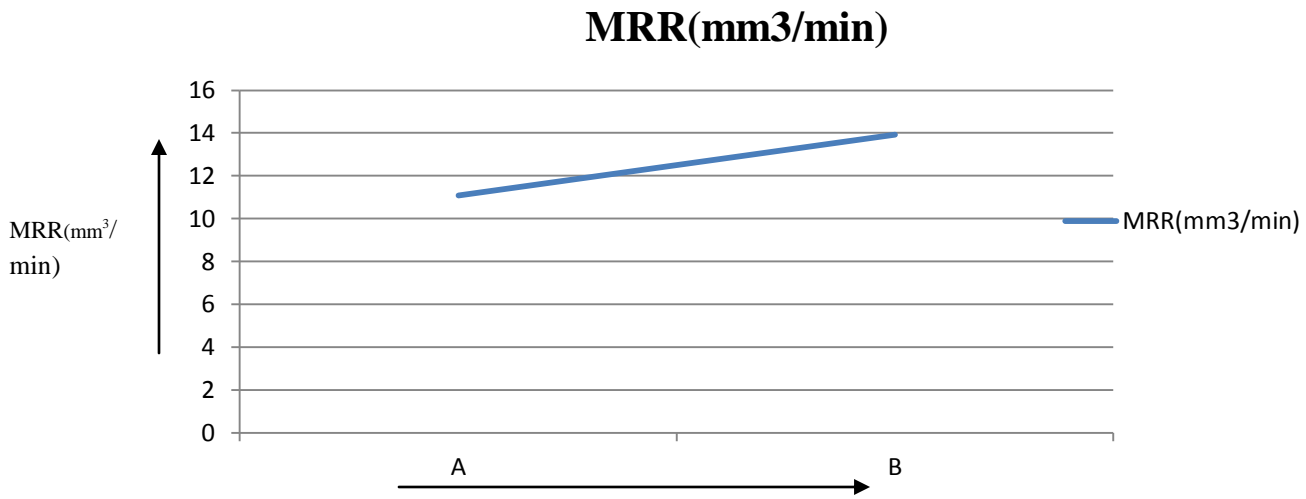


Figure 4.3 MRR without powder (A) and with powder (B)

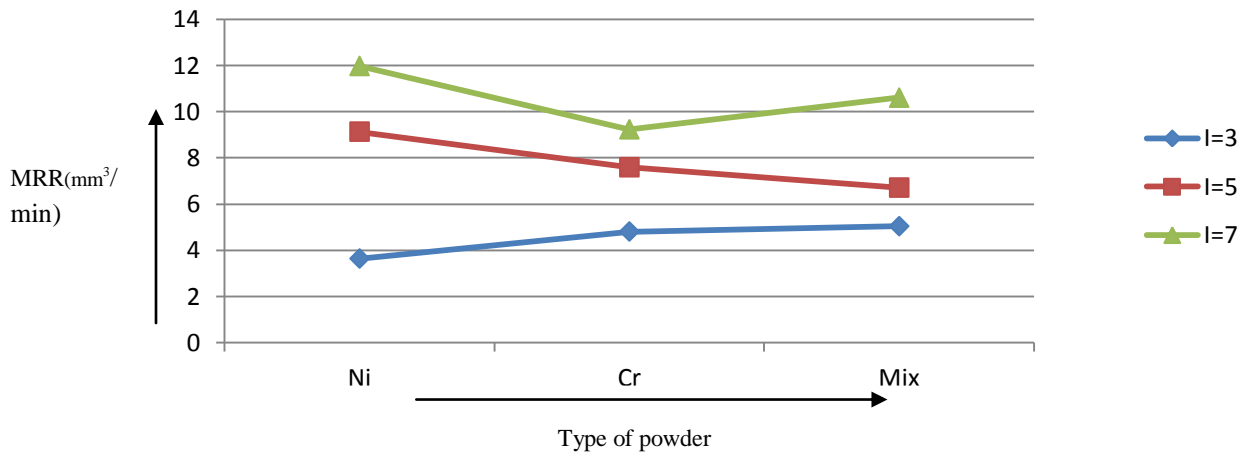


Figure 4.4 Individual effects of powders on MRR

RESULTS AND ANALYSIS FOR TWR

5.1 INTRODUCTION

The effect of parameters i.e. . tool, current, concentration, pulse on, pulse off, and powder were evaluated using ANOVA. The confidence interval of 95% has been used for analysis. One repetition for 18 trials was completed so as to measure signal to noise ratio (S/N Ratio).

5.2 RESULTS FOR TWR

The results for TWR for each of 18 treatment conditions with repetition are given in Table 5.1. TWR of each sample was calculated from weight difference of workpieces before and after the trial:

$$TWR = \frac{W_i - W_f}{\rho \times t} \times 1000 \text{ mm}^3 / \text{min}$$

Where

W_i = Initial weight of tool materials (gms)

W_f = Final weight of tool materials (gms)

t = Time period of trials in minutes (min)

ρ = Density of workpiece in gms/cc

Table 5.1: Results for TWR

S.No.	Tool	Current (A)	Concentration (g/l)	Pulse on (μ s)	Pulse off(μ s)	Powder	TWR(mm^3/min)		MEAN TWR (mm^3/min)	S/N Ratio
							1	2		
1	Cu	3	3	20	38	Ni	0.111	0.113	0.112	19.01
2	Cu	3	5	50	57	Cr	0.128	0.142	0.135	17.38
3	Cu	3	7	100	85	Mix	0.154	0.158	0.150	16.13
4	Cu	5	3	20	57	Cr	0.228	0.208	0.218	13.22
5	Cu	5	5	50	85	Mix	0.191	0.199	0.195	14.19
6	Cu	5	7	100	38	Ni	0.207	0.223	0.215	13.34
7	Cu	7	3	50	38	Mix	0.222	0.226	0.224	12.99
8	Cu	7	5	100	57	Ni	0.576	0.565	0.570	4.87
9	Cu	7	7	20	85	Cr	0.332	0.315	0.323	9.79
10	W	3	3	100	85	Cr	0.224	0.229	0.226	12.89
11	W	3	5	20	38	Mix	0.104	0.111	0.107	19.36
12	W	3	7	50	57	Ni	0.151	0.153	0.152	16.36
13	W	5	3	50	85	Ni	0.184	0.186	0.185	14.65
14	W	5	5	100	38	Cr	0.231	0.243	0.237	12.50
15	W	5	7	20	57	Mix	0.139	0.147	0.143	16.88
16	W	7	3	100	57	Mix	0.450	0.455	0.452	6.88
17	W	7	5	20	85	Ni	0.265	0.266	0.265	11.51
18	W	7	7	50	38	Cr	0.323	0.329	0.326	9.73

5.3 ANALYSIS OF VARIANCE FOR TWR

The results were analyzed using ANOVA for identifying the significance factors affecting the performance measures. The analysis of variance for mean TWR 95% confidence interval is given in table 5.2. The variation of data for each was F-tested to find significance of each. The principle of F-test is that larger the F- value for particular parameters, the greater the effect on performance characteristics due to change in that process parameter. ANOVA tables shows that current (F value 19.21), pulse on time (F value 6.40), powder (F value 2.26) are factor that are significantly affect TWR. All other

factor namely, tool, pulse off time and concentration were found to be insignificant. Table 5.3 shows the ranks of various factors in the terms of their relative significance. Current has highest rank, significantly highest contribution to TWR.

Table 5.2 Analysis of variance for TWR

Source	DF	SS	SS'	F	P
Tool	1	0.000131	0.000131	0.03	0.859
Current	2	0.146368	0.073184	19.21	0.002
Concentration	2	0.003351	0.0016675	0.44	0.663
Pulse on	2	0.048767	0.024384	6.40	0.033
Pulse off	2	0.017484	0.008742	2.29	0.182
Powder	2	0.004519	0.002259	0.59	0.582
Residual Error	6	0.022863	0.0038111		
Total	17	0.243482			

Table 5.3 Response table for TWR

Level	Tool	Current	Concentration	Pulse on	Pulse off	Powder
1	0.238	0.148	0.236	0.194	0.203	0.250
2	0.232	0.198	0.251	0.202	0.278	0.244
3		0.360	0.219	0.309	0.225	0.213
Delta	0.006	0.212	0.032	0.114	0.074	0.037
Rank	6	1	5	2	3	4

Figure 5.4 it can be observed that TWR increases with increase in discharge current for all the three processes. This may be due to more electrical discharge energy being conducted into the machining gap with the increase in discharge current, thereby increasing the TWR. Same is effect of pulse on time. With increase in pulse on time more, thermal energy enters into workpiece and more metal turns into liquid form, resulting in increasing TWR. As seen in figure 5.1, TWR increases with concentration. Because, the increase in the abrasive powder concentration also helps to bridge the gap between the tool electrode and the work material, thus increasing the rate of TWR. But

after level 2(5g/l) to level 3 (5g/l), TWR decreases, due to higher abrasive particle concentration with higher particle size display a discharge interference phenomenon. Mix powder at concentration 7g/l gives minimum TWR.

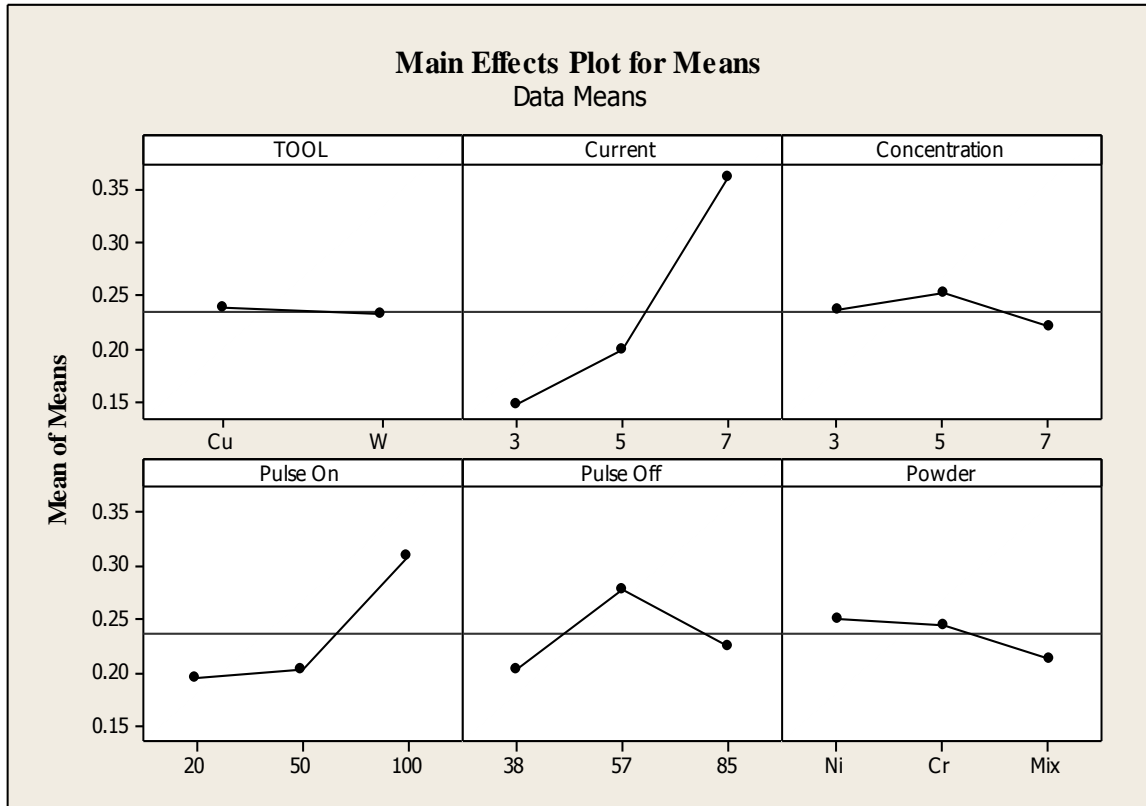


Figure 5.1 Main effects plot for Means for TWR

5.4 RESULTS FOR S/N RATIO OF TWR

The S/N ratio consolidates several repetitions into one value and is indication of amount of variation present. The S/N ratio has been calculated to identify the major contributing factors that cause variation in TWR. TWR is considered “Lower is better” which is given by:

- **Lower the Better**

$$(S/N)_{LB} = -10 \log (MSD_{LB})$$

Where $MSD_{LB} = \frac{1}{R} \sum_{j=1}^R (y_j^2)$

MSD_{LB} = Mean Square Deviation for Lower-the-better response

Table 5.4 Response table for S/N ratio of TWR

Level	Tool	Current	Concentration	Pulse on	Pulse off	Powder
1	17.04	12.89	16.26	15.16	16.76	17.13
2	16.82	17.63	17.30	16.26	17.04	16.76
3		20.27	17.23	19.37	17.00	16.90
Delta	0.22		1.04	4.22	0.28	0.37
	6	1	3	2	5	4

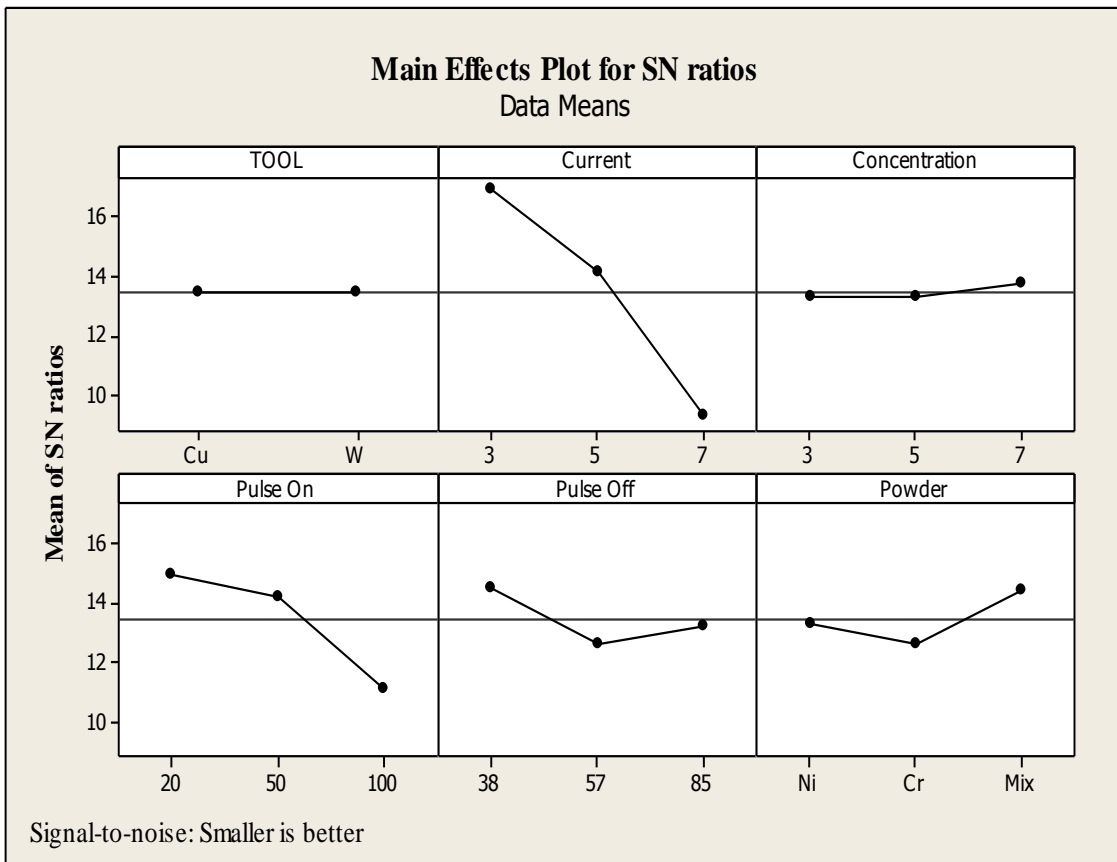


Figure 5.2 Main effect plot of S/N ratio for TWR

5.5 OPTIMAL DESIGN FOR TWR

In this experiment analysis, the main effect plot as shown in figure 5.1 was used to estimate the mean TWR. From the table, it is concluded that the lowest value of TWR was observed when H21 workpiece was machined at current (3A) and Pulse on time (20µs). In S/N ratio, the highest TWR was observed when workpiece was machined at current 3Amp and Pulse on time 100µs.

Table 5.5 Significant Factor for TWR

Factor	Affecting Mean		Affecting Variation	
	Contribution	Best Level	Contribution	Best Level
Tool, A	Insignificant		Insignificant	
Current, B	Significant	Level 1 (3 A)	Significant	Level 1 (3A)
Concentration, C	Insignificant		Insignificant	
Pulse on, D	Significant	Level 1 (20 µS)	Significant	Level 1 (20 µS)
Pulse off, E	Insignificant		Insignificant	
Powder, F	Insignificant		Insignificant	Insignificant

In experiment analysis, the TWR is the lowest average response is the best characteristic. Depending on characteristics, it has been chosen to obtain satisfactory results. After conducting the experiment, the optimum treatment conditions are selected to determine one of the experiments.

Mean value of TWR

$$\mu_{B_1D_1} = B_1 + D_1 - T$$

$$= 0.148 + 0.194 - 0.223 = 0.119 \text{ mm}^3/\text{min}$$

Confidence Interval around the estimated value

$$CI_1 = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{\eta_{eff}}}$$

Where F_{α, v_1, v_2} = F ratio

α = risk (0.05) confidence = 1- α

v_1 = degree of freedom for mean which is always = 1

v_2 = (Total degree's of freedom) - (degree's of freedom of significant factors)

V_e = (SS_{total}-SS_{significant factors}) / (total DOF – DOF of significant factors)

$$\eta_{eff} = \frac{N}{1 + dof_{A,c}} = \frac{18}{1 + 2 + 2} = 3.6$$

$$CI_1 = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{\eta_{eff}}} = \sqrt{\frac{4.67 \times 0.0037}{3.6}} = 0.069$$

So confidence interval around TWR is given by 0.119+/- 0.069 mm³/min

It has been observed from experimental data that the powder is not acting as a significant parameter. Therefore, to see the effect powder addition on TWR, we had conducted the experiments using optimal parameters with and without powder. It was observed that there was 45.35% decrease in TWR with addition of Mix powder (Nickel and Chromium). Following table 5.6 shows outcomes of experiment.

Table 5.6 Conformational experiment results

S.No.	Tool	Current (A)	Concentration (g/l)	Pulse on (μs)	Pulse off(μs)	Powder	TWR Without Powder (mm ³ /min)	TWR With Powder (mm ³ /min)
1	W	3	5	20	38	Ni	0.215	0.117

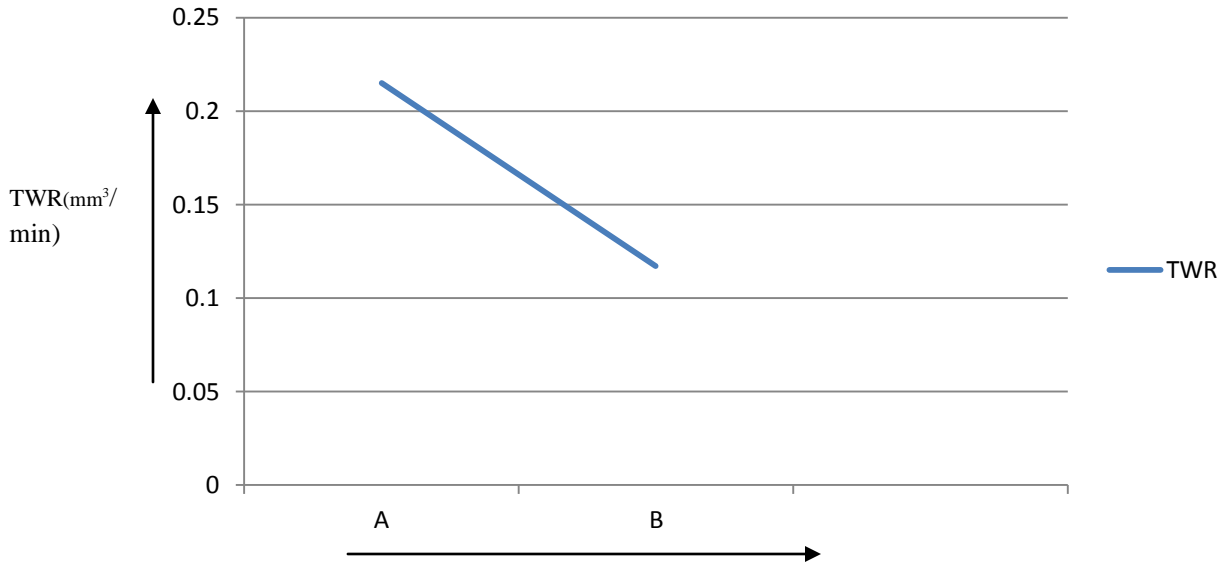


Figure 5.3 TWR without powder (A) and with powder (B)

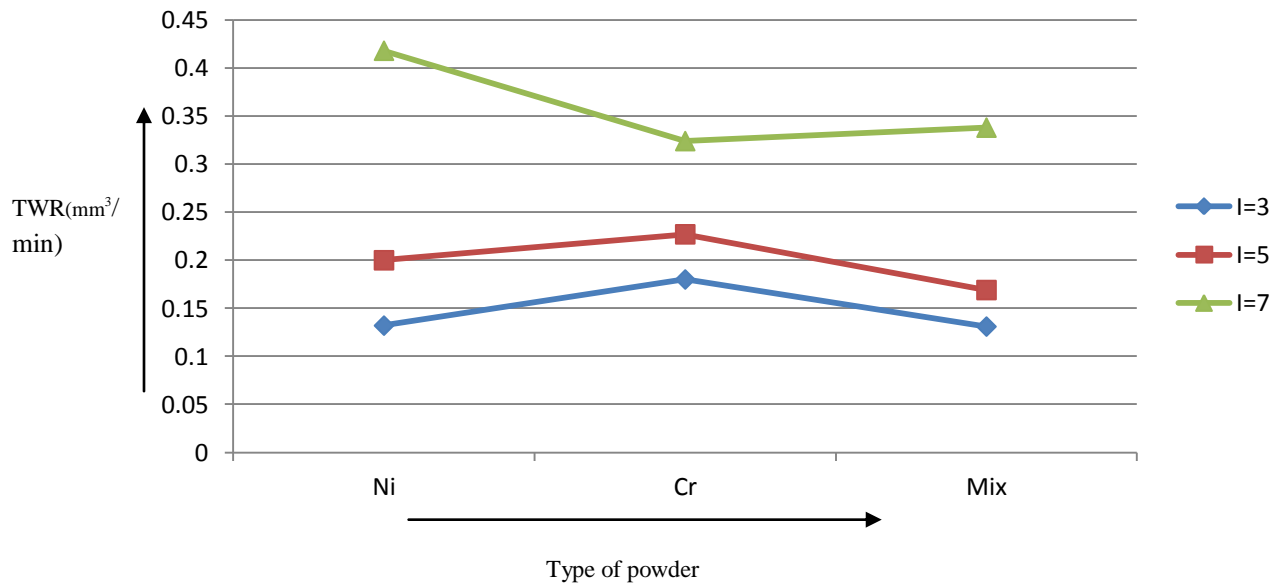


Figure 5.4 Individual effects of powders on TWR

RESULTS AND ANALYSIS FOR SURFACE ROUGHNESS

6.1 INTRODUCTION

In this experiment work surface roughness is measured at two positions i.e. . position 1 (centre) and position 2 (side of cut). First reading was taken centre of cut and second reading was taken at 5mm from first position 1 (centre) of cut. The results for surface roughness at position 1 (centre) for each of 18 treatment conditions with repetition are shown in table 6.1.

Table 6.1 Results for Surface Roughness

Trial No.	Tool	Current (A)	Concentration (g/l)	Pulse on (µs)	Pulse off (µs)	Powder	Roughness Position 1		Roughness Position 2	
							1	2	1	2
1	Cu	3	3	20	38	Ni	3.97	4.17	3.75	4.17
2	Cu	3	5	50	57	Cr	4.65	5.06	4.57	4.91
3	Cu	3	7	100	85	Mix	5.87	5.96	6.07	5.99
4	Cu	5	3	20	57	Cr	4.79	4.84	4.87	4.98
5	Cu	5	5	50	85	Mix	5.13	5.32	5.17	5.09
6	Cu	5	7	100	38	Ni	6.61	6.97	6.63	6.79
7	Cu	7	3	50	38	Mix	8.28	8.34	8.51	8.39
8	Cu	7	5	100	57	Ni	10.23	10.27	10.71	11.09
9	Cu	7	7	20	85	Cr	8.04	7.89	7.93	7.81
10	W	3	3	100	85	Cr	6.68	6.57	6.55	6.43
11	W	3	5	20	38	Mix	2.98	3.27	3.12	4.62
12	W	3	7	50	57	Ni	5.17	5.33	4.98	5.17
13	W	5	3	50	85	Ni	6.45	6.35	6.34	6.19
14	W	5	5	100	38	Cr	8.17	8.05	8.21	8.25
15	W	5	7	20	57	Mix	5.54	5.41	5.45	5.62
16	W	7	3	100	57	Mix	9.63	9.62	9.28	9.66
17	W	7	5	20	85	Ni	6.73	6.79	6.13	6.47
18	W	7	7	50	38	Cr	7.67	7.75	8.07	7.76

6.2 ANALYSIS OF VARIANCE FOR SURFACE ROUGHNESS (R_a) AT POSITION 1

The results were analyzed using ANOVA for identifying the significance factors affecting the performance measures. The analysis of variance for mean surface roughness 95% confidence interval is given in table 6.2. The variation of data for each was F-tested to find significance of each. The principle of F-test is that larger the F- value for particular parameters, the greater the effect on performance characteristics due to change in that process parameter. ANOVA tables shows that current (F value 37.32), pulse on time (F value 19.48), powder (F value 0.50) are factor that are significantly affect SR. All other factor namely, tool, pulse off time and concentration were found to be insignificant. Table 6.3 shows the ranks of various factors in the terms of their relative significance. Current has highest rank, significantly highest contribution to SR.

Table 6.2 Analysis of variance for SR

Source	DF	SS	SS'	F	P
Tool(A)	1	0.043	0.04	0.09	0.778
Current(B)	2	37.27	18.63	37.32	0.001
Concentration(C)	2	0.19	0.09	0.19	0.830
Pulse on(D)	2	19.46	9.73	19.48	0.002
Pulse off(E)	2	0.39	0.19	0.40	0.685
Powder(F)	2	0.52	0.26	0.50	0.615
Residual Error	6	2.99	0.49		
Total	17	60.9			

Table 6.3 Response table for surface roughness at position-1

Level	Tool	Current	Concentration	Pulse on	Pulse off	Powder
1	6.46	4.97	6.64	5.36	6.35	6.55
2	6.56	6.13	6.38	6.29	6.71	6.68
3		8.43	6.51	7.88	6.48	6.27
Delta	0.09	3.46	0.25	2.51	0.35	0.40
Rank	6	1	5	2	4	3

Figure 6.1 it can be observed that SR increases with increase in discharge current for all the three processes. As the discharge current increases, the discharge energy density and the impulsive force increase and results in the formation of deeper and larger discharge craters, which in turn increases surface roughness. The SR also increases with increase in pulse on time. It is found that the discharge energy increases with peak current. The material removal rate is thus higher and the surface roughness becomes worse. Mix powder gives lowest SR among other powder (Chromium and Nickel).It means that combine effect of nickel and chromium is best on surface of workpiece from individual effect of chromium and nickel powder.

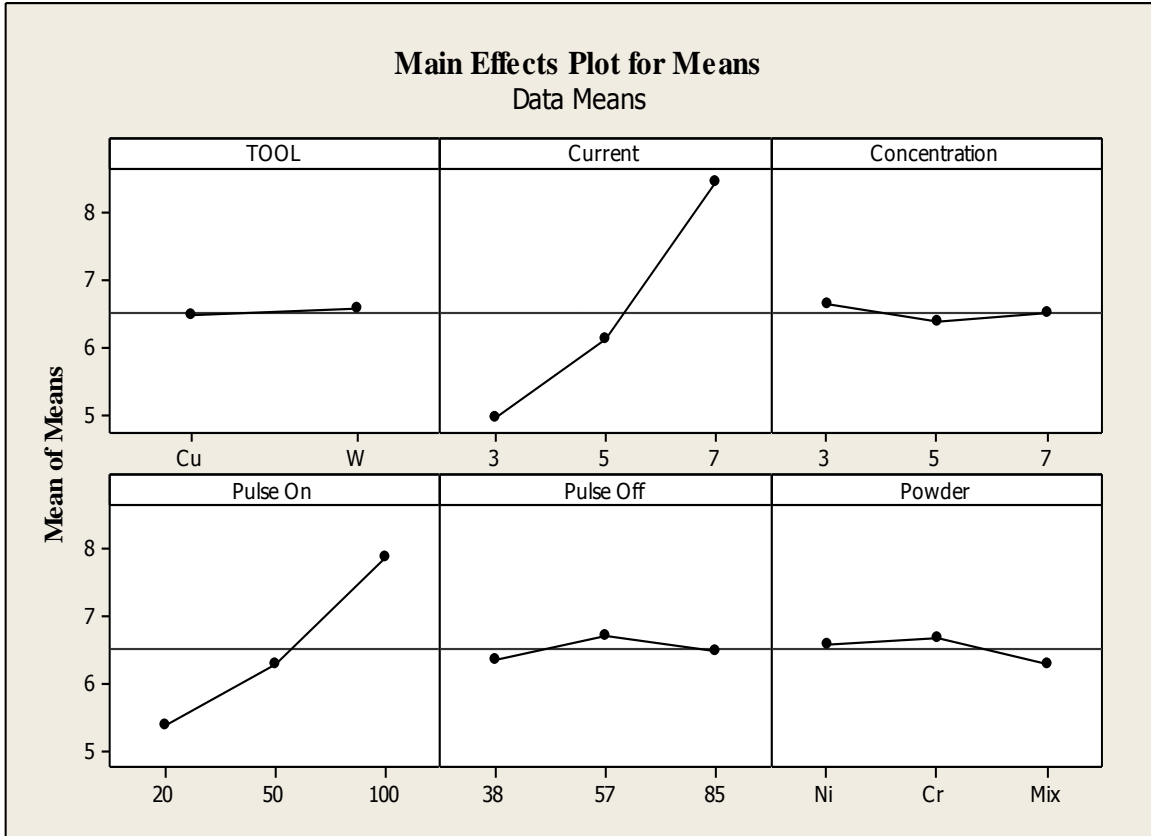


Figure 6.1 Main effects plot for Means of surface roughness at position 1

6.3 RESULTS FOR S/N RATIO OF SURFACE ROUGHNESS (R_a) AT POSITION 1

The S/N ratio consolidates several repetitions into one value and is indication of amount of variation present. The S/N ratios have been calculated to identify the major contributing factors that cause variation in SR. SR is considered “Lower is better” which is given by:

- **Lower the Better**

$$(S/N)_{LB} = -10 \log (MSD_{LB})$$

$$\text{Where } MSD_{LB} = \frac{1}{R} \sum_{j=1}^R (y_j^2)$$

MSD_{LB} = Mean Square Deviation for Lower-the-better response

Table 6.4 Response table for S/N ratio of surface roughness

Level	Tool	Current	Concentration	Pulse on	Pulse off	Powder
1	-15.85	-13.68	-16.08	-14.19	-15.51	-16.03
2	-15.98	-15.62	-15.50	-15.79	-16.07	-16.29
3		-18.44	-16.17	-17.76	-16.16	-15.42
Delta	0.13	4.76	0.67	3.57	0.65	0.67
RANK	6	1	4	2	5	3

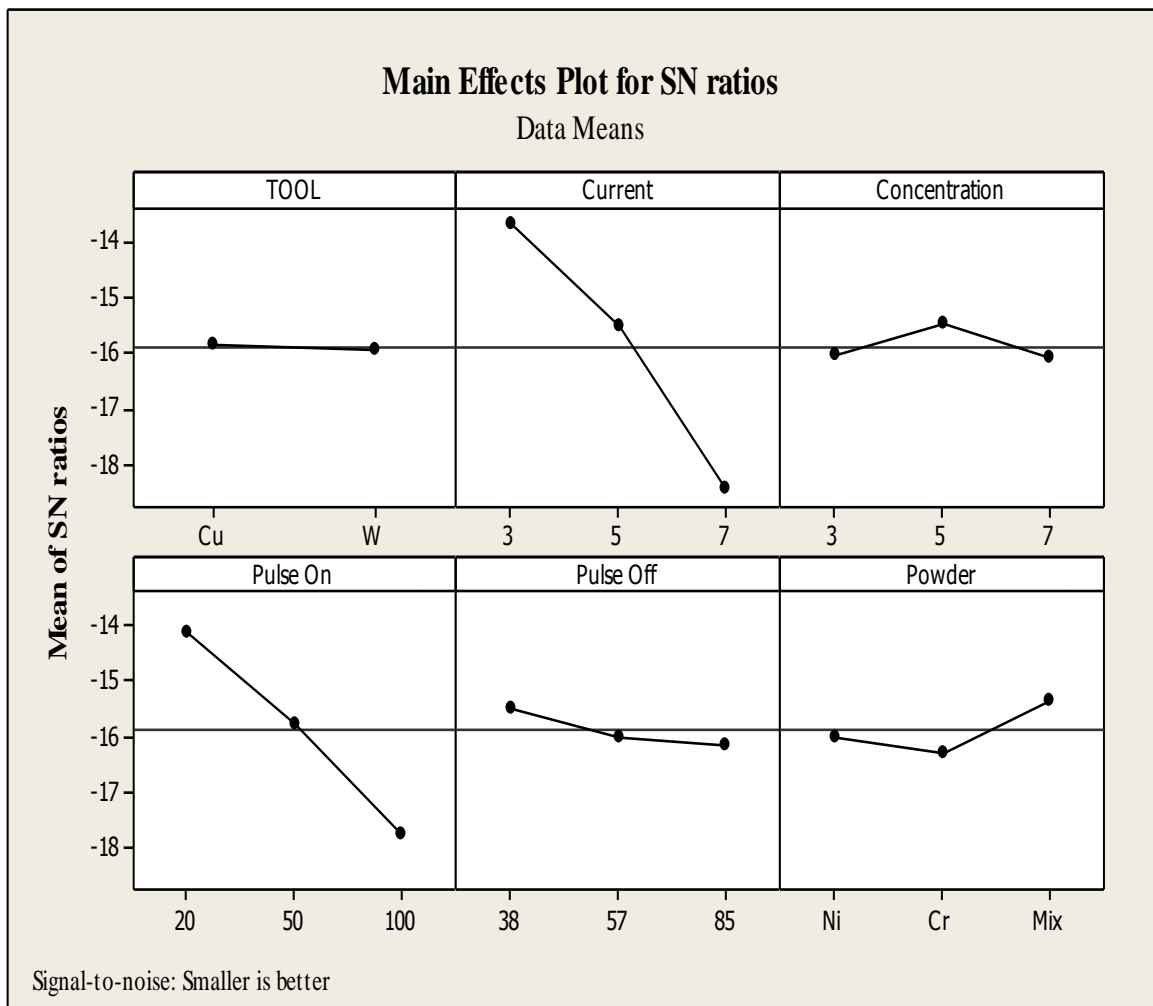


Figure 6.2 Main effect plot of S/N ratio of surface roughness at position 1

6.4 OPTIMAL DESIGN FOR SURFACE ROUGHNESS (R_a) AT POSITION 1

In this experiment analysis, the main effect plot as shown in figure 6.1 was used to estimate the mean surface roughness. From the table, it is concluded that the lowest value of surface roughness was observed when H21 workpiece was machined at current (3A) and Pulse on time (20 μs). In S/N ratio, the highest surface roughness was observed when workpiece was machined at current at level 1 (3A) and pulse on time level 1 (20 μs).

Table 6.5 Significant Factor for SR for position 1

Factor	Affecting Mean		Affecting Variation	
	Contribution	Best Level	Contribution	Best Level
Tool, A	Insignificant		Insignificant	
Current, B	Significant	Level 1 (3 A)	Significant	Level 1 (3A)
Concentration, C	Insignificant		Insignificant	
Pulse on, D	Significant	Level 1 (20 μS)	Significant	Level 1 (20 μS)
Pulse off, E	Insignificant		Insignificant	
Powder, F	Insignificant		Insignificant	Insignificant

In experiment analysis, the surface roughness is the lowest response is the best characteristic. Depending on characteristics, it has been chosen to obtain satisfactory results. After conducting the experiment, the optimum treatment conditions are selected to determine one of the experiments to optimum surface roughness.

Mean value of Surface Roughness

$$\mu_{B_1D_1} = B_1 + D_1 - T$$

$$= 4.97 + 5.36 - 6.51 = 3.82 \text{ micron } (\mu\text{m})$$

Confidence Interval around the estimated value

$$CI_1 = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{\eta_{eff}}}$$

Where F_{α, v_1, v_2} = F ratio

α = risk (0.05) confidence = 1- α

v_1 = degree of freedom for mean which is always = 1

v_2 = (Total degree's of freedom) - (degree's of freedom of significant factors)

V_e = $(SS_{total} - SS_{significant\ factors}) / (total\ DOF - DOF\ of\ significant\ factors)$

$$\eta_{eff} = \frac{N}{1 + dof_{A,c}} = \frac{18}{1 + 2 + 2} = 3.6$$

$$CI_1 = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{\eta_{eff}}} = \sqrt{\frac{4.67 \times 0.32}{3.6}} = 0.64$$

So confidence interval around surface roughness is given by 3.82+/- 0.64 micron

6.5 ANALYSIS OF VARIANCE FOR SURFACE ROUGHNESS (R_a) POSITION 2 (At side of cut)

The results for surface roughness at position 2 (side of cut) for each the 18 treatments condition with repetition is given in Table 6.1. The experiment results for surface roughness were analyzed using ANOVA for identifying the significant factors affecting the performance measures. ANOVA for mean surface roughness at 95% confidence interval in Table 6.6. The current and pulse on time are two input parameters which

effects the surface roughness. The surface roughness increases with current increases 3A to 7A. The surface roughness increases with pulse on time increases. Table 6.7 shows the ranks to various factors according to significance in surface roughness. The current has higher contribution in surface roughness.

Table 6.6 ANOVA for surface roughness at position 2

Source	DF	SS	V	F	P
Tool	1	0.01	0.010	0.01	0.908
Current	2	37.39	18.69	25.97	0.001
Concentration	2	0.01	0.009	0.01	0.987
Pulse on	2	20.42	10.21	14.18	0.005
Pulse off	2	0.55	0.27	0.38	0.697
Powder	2	2.38	0.11	0.17	0.851
Residual Error	6	4.32	0.72		
Total	17	62.95			

Table 6.7 Response table for means of surface roughness at position 2

Level	Tool	Current	Concentration	Pulse on	Pulse off	Powder
1	6.52	5.02	6.59	5.41	6.52	6.53
2	6.57	6.13	6.52	5.26	6.77	6.69
3		8.48	6.52	7.97	6.34	6.41
Delta	0.048	3.45	0.07	2.56	0.42	0.28
Rank	6	1	5	2	3	4

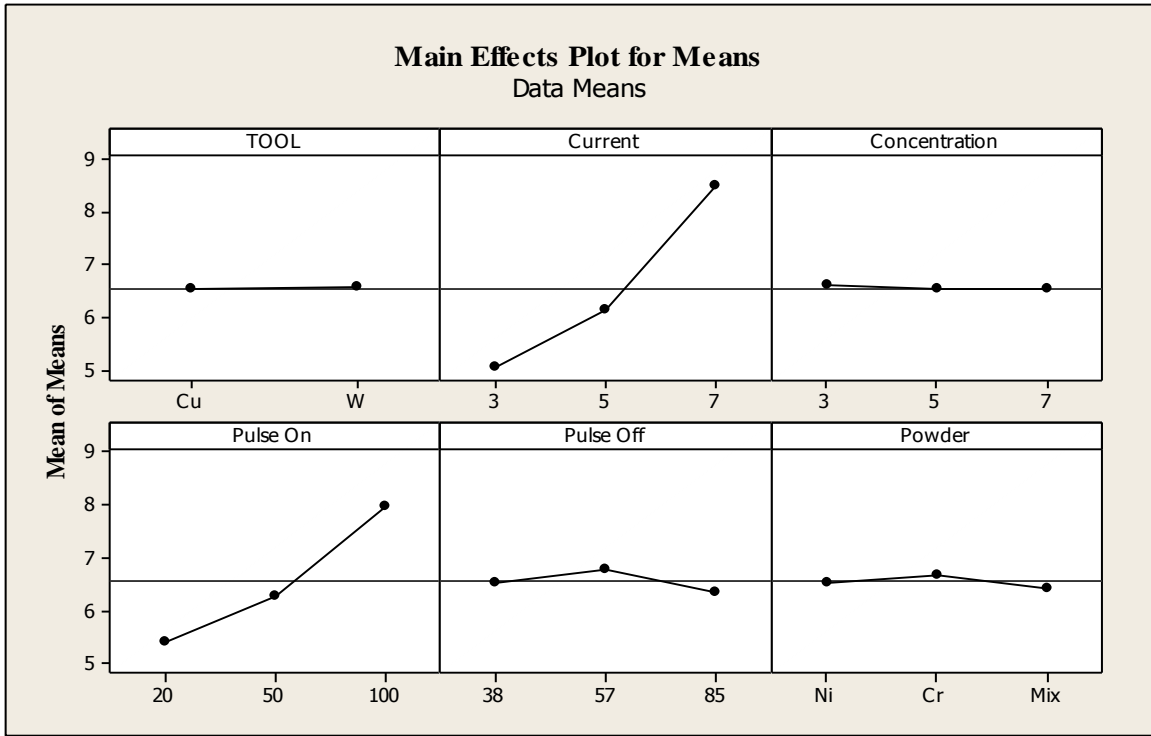


Figure 6.3 Main effects plot for surface roughness at position 2

6.6 ANOVA FOR S/N RATIO FOR SURFACE ROUGHNESS (R_a) AT POSITION- 2

The S/N reflects the amount of variation present in several repetitions. The value of all the results according to Taguchi array parameter design layout is presented in this section. The S/N ratios have been calculated to identify the major contributing factors. In this design, roughness is the type of “Lower is better”, which is logarithmic functions based on mean square deviation (MSD), given by:

- **Lower the Better**

$$(S/N)_{LB} = -10 \log (\text{MSD}_{LB})$$

$$\text{Where } \text{MSD}_{LB} = \frac{1}{R} \sum_{j=1}^R (y_j^2)$$

MSD_{LB} = Mean Square Deviation for Lower-the-better response

Table 6.8 shows the responses for S/N ratio for roughness 95% confidence interval. Among all the factor current, pulse on and powder are significant. Current has most significant which has highest contribution in roughness.

Table 6.8 Response table for S/N ratio of surface roughness at position 2

Level	Tool	Current	Concentration	Pulse on	Pulse off	Powder
1	-15.88	-13.89	-16.01	-14.42	-15.87	-15.88
2	-16.10	-15.62	-15.78	-15.71	-16.10	-16.30
3		-18.45	-16.17	-17.83	-15.98	-15.78
Delta	0.22	4.56	0.39	3.41	0.23	0.53
Rank	6	1	4	2	5	3

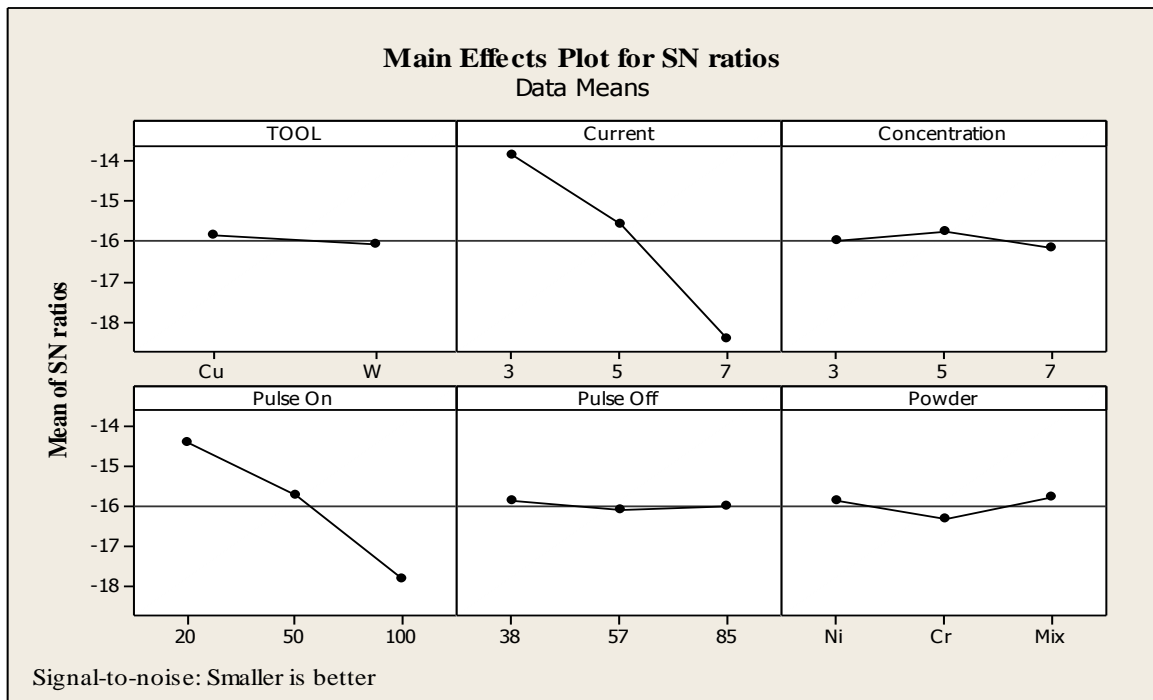


Figure 6.4 Main effects plot for S/N ratio of surface roughness at position 2

6.7 OPTIMAL DESIGN FOR SURFACE ROUGHNESS (R_a) AT POSITION 2

In this experiment analysis, the main effect plot as shown in figure 6.1 was used to estimate the mean surface roughness. From the table, it is concluded that the lowest value of surface roughness was observed when H21 workpiece was machined at current (3A) and Pulse on time (20 μs). In S/N ratio, the highest surface roughness was observed when workpiece was machined at current at level 1 (3A) and pulse on time 20μs.

Table 6.10 Significant Factor for SR at position 2

Factor	Affecting Mean		Affecting Variation	
	Contribution	Best Level	Contribution	Best Level
Tool, A	Insignificant		Insignificant	
Current, B	Significant	Level 1 (3 A)	Significant	Level 1 (3A)
Concentration, C	Insignificant		Insignificant	
Pulse on, D	Significant	Level 1 (20 μs)	Significant	Level 1 (20 μs)
Pulse off, E	Insignificant		Insignificant	
Powder, F	Insignificant		Insignificant	Insignificant

In experiment analysis, the surface roughness is the lowest response is the best characteristic. Depending on characteristics, it has been chosen to obtain satisfactory results. After conducting the experiment, the optimum treatment conditions are selected to determine one of the experiments.

Mean value of Surface Roughness

$$\mu_{B_1D_1} = B_1 + D_1 - T$$

$$= 5.02 + 5.47 - 6.51 = 3.98 \text{ micron}$$

Confidence Interval around the estimated value

$$CI_1 = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{\eta_{eff}}}$$

α = risk (0.05) confidence = 1- α

v_1 = degree of freedom for mean which is always = 1

v_2 = (Total degree's of freedom) - (degree's of freedom of significant factors)

V_e = (SS_{total}-SS_{significant factors}) / (total DOF – DOF of significant factors)

$$\eta_{eff} = \frac{N}{1 + dof_{A,c}} = \frac{18}{1 + 2 + 2} = 3.6$$

$$CI_1 = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{\eta_{eff}}} = \sqrt{\frac{4.67 \times 0.39}{3.6}} = 0.71$$

So confidence interval around surface roughness is given by 3.98+/- 0.71 micron

It has been observed from experimental data that the powder is not acting as a significant parameter. Therefore, to see the effect powder addition on SR, we had conducted the experiments using optimal parameters with and without powder. It was observed that there was 17.64% decrease in SR with addition of Mix powder. Following table 6.11 showed outcomes of experiment.

Table 6.11 Conformational experiment results

S.No.	Tool	Current (A)	Concentration (g/l)	Pulse on (µs)	Pulse off(µs)	Powder	SR Without Powder (micron)	SR With Powder (micron)
1	Cu	3	5	20	85	Mix	5.27	4.34

Surface Roughness(micron)

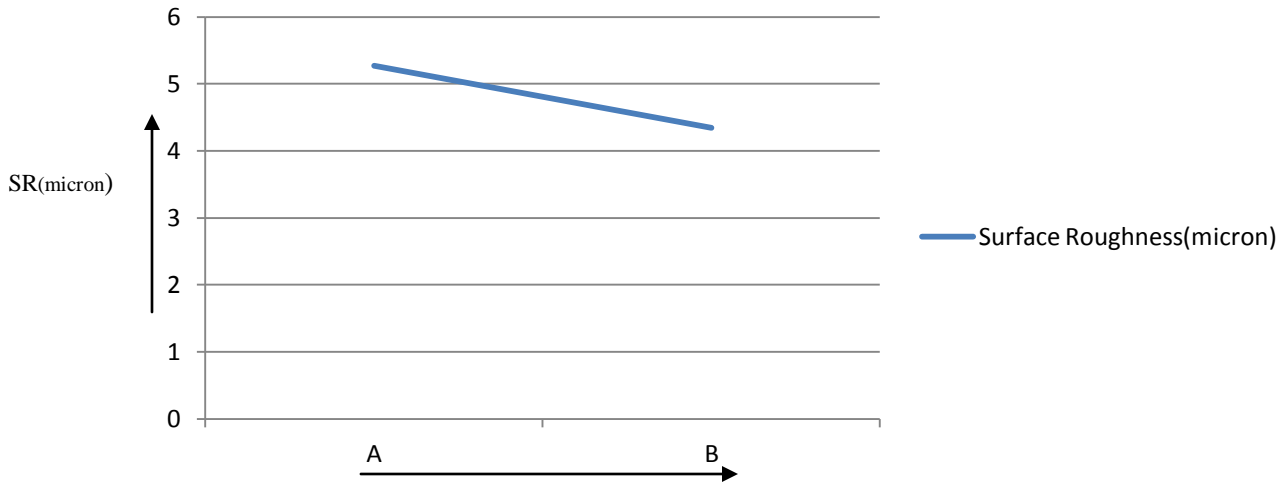


Figure 6.5 SR without powder (A) and with powder (B)

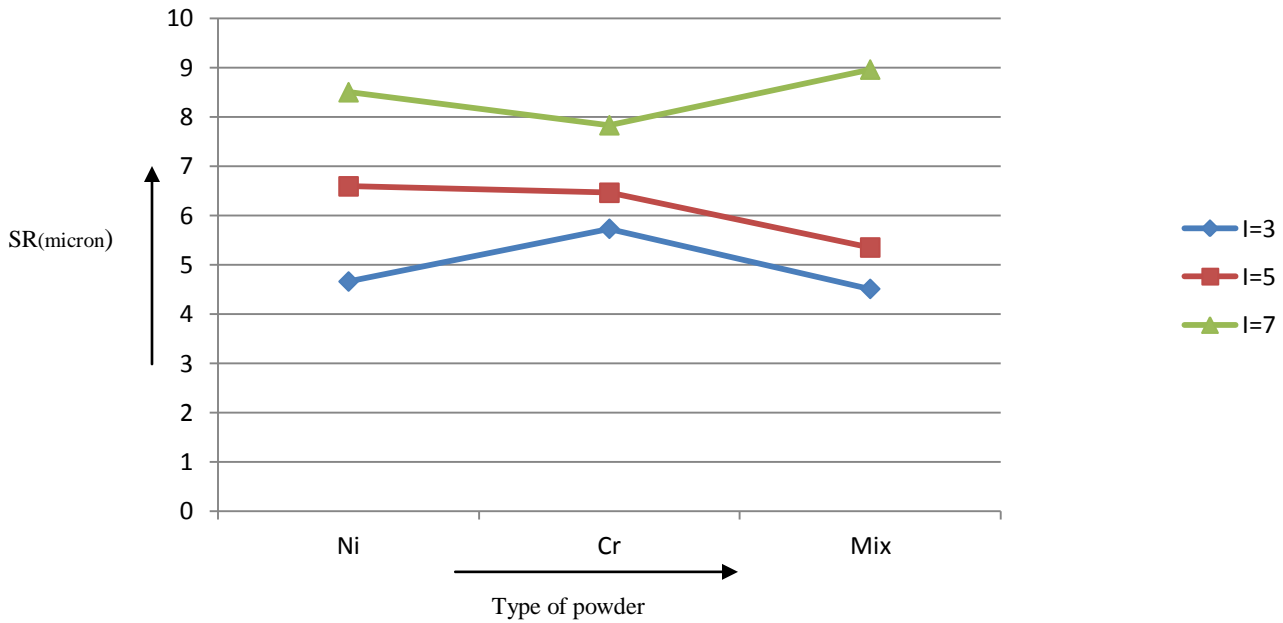


Figure 6.6 Individual effects of powders on SR

From figure 6.5 it has been observed that mix powder gives best SR at lowest level of current (3A).

RESULTS ANALYSIS FOR MICROHARDNESS

7.1 INTRODUCTION

The effect of parameters i.e. . tool, current, concentration, pulse on, pulse off, and powder were evaluated using ANOVA. The confidence interval of 95% has been used for analysis. One repetition for 18 trials was completed so as to measure signal to noise ratio (S/N Ratio). The microhardness measurement is dependent of diameter of indentation on samples. The indent formed in pyramid shaped indenter was measured with Quantimet software using a load of 1Kg for 20 seconds. The results for microhardness for each of the 18treatment condition with repetition are shown in Table 7.1.

Table 7.1 Results for Microhardness

Trial No.	Tool	Current (A)	Concentration (g/l)	Pulse On (µs)	Pulse Off (µs)	Powder	Microhardnes (hvn)		MEAN Micro-Hardness (hvn)	S/N Ratio
							1	2		
1	Cu	3	3	20	38	Ni	131.89	133.71	132.80	42.46
2	Cu	3	5	50	57	Cr	149.29	145.87	147.58	43.37
3	Cu	3	7	100	85	Mix	208.56	205.39	206.97	46.31
4	Cu	5	3	20	57	Cr	192.43	186.84	189.63	45.55
5	Cu	5	5	50	85	Mix	195.37	199.45	197.41	45.90
6	Cu	5	7	100	38	Ni	177.63	169.57	173.60	44.78
7	Cu	7	3	50	38	Mix	239.49	240.24	239.86	47.59
8	Cu	7	5	100	57	Ni	209.35	205.93	207.64	46.34
9	Cu	7	7	20	85	Cr	247.73	255.48	251.60	48.01
10	W	3	3	100	85	Cr	189.51	197.19	193.35	45.72
11	W	3	5	20	38	Mix	158.74	160.33	159.53	44.05
12	W	3	7	50	57	Ni	129.06	127.94	128.50	42.17
13	W	5	3	50	85	Ni	170.23	179.97	175.10	44.85
14	W	5	5	100	38	Cr	330.68	332.17	331.42	50.40
15	W	5	7	20	57	Mix	217.78	213.46	215.62	46.67
16	W	7	3	100	57	Mix	244.15	250.85	247.50	47.86
17	W	7	5	20	85	Ni	228.73	230.27	229.50	47.21
18	W	7	7	50	38	Cr	276.47	286.84	281.65	48.98

7.3 ANALYSIS OF VARIANCE FOR MICROHARDNESS

The results were analyzed using ANOVA for identifying the significance factors affecting the performance measures. The analysis of variance for mean microhardness 95% confidence interval is given in table 7.2. The variation of data for each was F-tested to find significance of each. The principle of F-test is that larger the F- value for particular parameters, the greater the effect on performance characteristics due to change in that process parameter. ANOVA tables shows that current (F value 11.04), and powder (F value 5.57) are factor that are significantly affect microhardness. All other factor namely, tool, pulse on time, pulse off time and concentration were found to be insignificant. Table 7.3 shows the ranks of various factors in the terms of their relative significance. Current has highest rank, significantly highest contribution to microhardness.

Table 7.2 Analysis of variance for microhaedness

Source	DF	SS	SS'	F	P
Tool(A)	1	2569.8	2569.8	2.77	0.147
Current(B)	2	20466.1	10233.0	11.04	0.010
Concentration(C)	2	865.4	432.7	0.47	0.648
Pulse on(D)	2	3853.8	1926.9	2.08	0.206
Pulse off(E)	2	2849.3	1424.6	1.54	0.289
Powder(F)	2	10330.5	5165.3	5.57	0.043
Residual Error	6	5560.1	926.7	926.7	
Total	17	46494.9			

Table 7.3 Response table for Microhardness

Level	Tool	Current	Concentration	Pulse on	Pulse off	Powder
1	194.1	161.5	196.4	196.4	219.8	174.5
2	218.0	213.8	212.2	195.0	189.4	232.5
3		243.0	209.7	226.7	209.0	211.2
Delta	23.9	81.5	15.8	31.3	30.4	58.0
Rank	5	1	6	3	4	2

Figure 7.1, effect of various factors i.e. current, pulse on time, pulse off time; concentration of powder, tool and powder is shown in material removal rate. It is clear from graph that as current increases, Microhardness goes on increasing. This could be due to an increase in discharge energy with increase in discharge current, which improves the rate of melting. As we seen that powder significantly effected microhardness of workpiece. Chromium powder gives maximum microhardness than other powders.

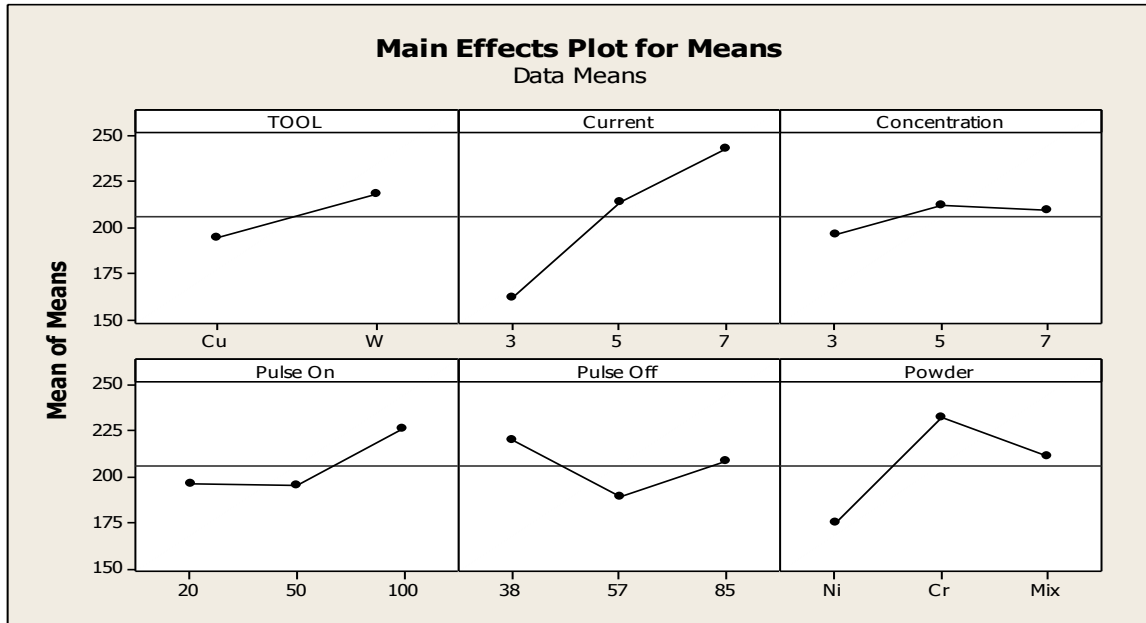


Figure 7.1 Main effects plot for Means for microhardness

7.4 RESULTS FOR S/N RATIO OF MICROHARDNESS

The S/N ratio consolidates several repetitions into one value and is indication of amount of variation present. The S/N ratio has been calculated to identify the major contributing factors that cause variation in microhardness. Microhardness is considered “Higher is better” which is given by:

- **Higher the Better**

$$(S/N)_{HB} = -10 \log (MSD_{HB})$$

$$\text{Where } MSD_{HB} = \frac{1}{R} \sum_{j=1}^R \left(\frac{1}{y_j^2} \right)$$

MSD_{HB} = Mean Square Deviation for higher-the-better response

Table 7.4 Response table for S/N ratio of Microhardness

Level	Tool	Current	Concentration	Pulse on	Pulse off	Powder
1	45.60	44.02	45.68	45.66	46.38	44.64
2	46.44	46.36	46.22	45.48	45.33	47.01
3		47.67	46.16	46.91	46.34	46.40
Delta	0.85	3.65	0.54	1.42	1.05	2.37
	5	1	6	3	4	2

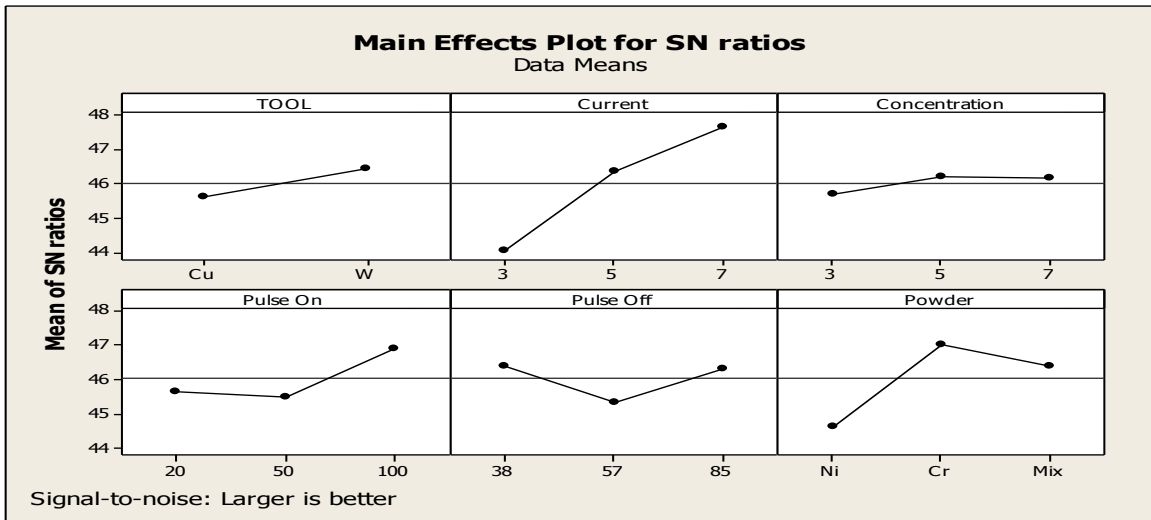


Figure 7.2 Main effect plot of S/N ratio for microhardness

7.5 OPTIMAL DESIGN FOR MICROHARDNESS

In this experiment analysis, the main effect plot as shown in figure 7.1 was used to estimate the mean microhardness. From the table, it is concluded that when H21 workpiece was machined at current (7A) and powder (Chromium). In S/N ratio highest microhardness was observed when workpiece was machined at current 7A. And Pulse on time 100 μ s. Significant factors are shown in table 7.5.

Table 7.5 Significant Factor for microhardness

Factor	Affecting Mean		Affecting Variation	
	Contribution	Best Level	Contribution	Best Level
Tool, A	Insignificant	-	Insignificant	-
Current, B	Significant	Level 3 (7 A)	Significant	Level 3 (7 A)
Concentration, C	Insignificant	-	Insignificant	-
Pulse on , D	Insignificant	-	Insignificant	-
Pulse off, E	Insignificant	-	Insignificant	-
Powder, F	Significant	Level 2(Chromium)	Significant	Level2(Chromium)

In experiment analysis the Microhardness is higher average response is better characteristic. Depending on characteristics has chosen to obtain satisfactory results. After conducting the experiment, the optimum treatment conditions are selected to determine one of experiment to get optimum treatment.

Mean value of Microhardness

$$\begin{aligned} \mu_{B_3F_2} &= B_3 + F_2 - T \\ &= 243.0 + 232.5 - 206.07 = 269.43 \text{ hvn} \end{aligned}$$

Confidence Interval around the estimated value

$$CI_1 = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{\eta_{eff}}}$$

Where $F_{\alpha, v_1, v_2} = F$ ratio

α = risk (0.05) confidence = 1- α

v_1 = degree of freedom for mean which is always = 1

v_2 = (Total degree's of freedom) - (degree's of freedom of significant factors)

V_e = ($SS_{\text{total}} - SS_{\text{significant factors}}$) / (total DOF – DOF of significant factors)

$$\eta_{eff} = \frac{N}{1 + dof_{A,c}} = \frac{18}{1 + 2 + 2} = 3.6$$

$$CI_1 = \sqrt{\frac{F_{\alpha, v_1, v_2} V_e}{\eta_{eff}}} = \sqrt{\frac{4.67 \times 1207.56}{3.6}} = 23.66$$

So confidence interval around Microhardness is given by 269.43+/- 23.66 hvn

8.1 INTRODUCTION

The effect of parameters i.e. . tool, current, concentration, pulse on time, pulse off time and powder were evaluated using ANOVA and Taguchi design analysis. The purpose of ANOVA was to identify the important parameters in prediction of MRR, TWR, surface roughness and microhardnes. Some results consolidated from ANOVA.

8.2 MATERIAL REMOVAL RATE

From the experiment, it was observed that current was found to be most significant factor and followed by pulse on time were factors that significantly affected MRR. All other factors namely tool, pulse off time were found to be insignificant to MRR.

To see the effect of powder on MRR, there was further conducted experiment. It was found that with addition of Nickel powder to dielectric, it increases MRR by 25.58%. The best results for MRR would be achieved when workpiece was machined at current 7 A and pulse on time 100 μ s with copper tungsten electrode and nickel powder mixing in dielectric. With 95% confidence interval was found to be 12.95 \pm 1.21 mm³/min.

8.3 TOOL WEAR RATE

It was observed that current was found to be most significant factor and followed by pulse on time were factors that significantly affected TWR. All other factors namely tool, pulse off time were found to be insignificant to TWR.

Therefore, to see the effect powder addition on TWR, we had conducted the experiments using optimal parameters with and without powder. It was observed that there was

45.58% decrease in TWR with addition of Mix powder. With 95% confidence interval was found to be $0.119 \pm 0.069 \text{ mm}^3/\text{min}$.

8.4 SURFACE ROUGHNESS

It was observed that current was found to be most significant factor and followed by pulse on time were factors that significantly affected SR. All other factors namely tool, pulse off time were found to be insignificant to SR.

Therefore, to see the effect powder addition on SR, we had conducted the experiments using optimal parameters with and without powder. It was observed that there was 17.64% decrease in SR with addition of Mix powder. With 95% confidence interval was found to 3.98 ± 0.71 micron.

8.5 MICROHARDNESS

From the experiment, it was observed that current was found to be most significant factor and followed by powder were factors that significantly affected microhardness. All other factors namely tool, pulse on, pulse off time were found to be insignificant to microhardness.

The best results for microhardness would be achieved when workpiece was machined at current 7A and with copper tungsten electrode and chromium powder mixing in dielectric. With 95% confidence interval was found to be 269.43 ± 23.66 hvn.

8.6 CONCLUSIONS

The present study was carried out to study the effect of input parameters on MRR, TWR, surface roughness and microhardness. The following conclusions have been drawn from study:

- Nickel powder gives better MRR than chromium powder.
- MRR and TWR are mainly affected by the current and pulse on time.
- With addition of Nickel powder to dielectric it increases the MRR by 25.58%.
- TWR decreased with addition of mix (Nickel and Chromium) powder by 45.85%.

- Microhardness was affected by current and powder.
- Surface roughness decreased with addition of mix (Nickel and Chromium) powder by 17.64%. Mix powder is more effective than pure Nickel and Chromium powder.
- Chromium powder gives maximum microhardness at concentration 5g/l than nickel and mix powder.
- Surface roughness is mainly effected by current and pulse on time.
- Surface roughness can be decreased with mix powder Nickel and Chromium at concentration of 5g/l.

8.7 FUTURE WORK

There are following recommendation for future work:

- In the present study H21 (Hot die steel) was used for EDM cutting. Study can be further extended to other materials like Titanium, Cobalt Tungsten and other metal matrix.
- In the present study Nickel and Chromium powders were used to see their effect on surface properties on workpiece material. Study can be further extended to see the effect of vanadium and boron carbide on above discussed material.
- Study can be further extended to see effect of particle grit size and dielectric flow in EDM.

CHAPTER 9

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TECHNICAL SPECIFICATION OF EDM MACHINE

The experiments has been conducted on Electrical Discharge Machine (Model: T-3822M), Victory Electromech, India. Technical data of machine is as under:

Electrical Data

Supply voltage	415 V, 3 Φ , 50 Hz
Connected load	3 KVA
Open gap voltage output	(135 \pm 5) % V
Maximum machine current	12 A
Current range	3 ranges of 4 A each

SPECIFICATION OF DIELECTRIC MEDIUM

EDM oil

Appearance	Clear, light
Density (Kg/m ³)	835
Flash point (°C)	130
Viscosity	3.12
Specific gravity (cSt)	0.78 \pm 0.02
Dielectric strength	45 kV

SPECIFICATIONS OF MEASURING INSTRUMENTS

1. PROFILE PROJECTOR

Model and make	V-10A, Japan
Voltage requirement	220 V / 230 V / 240 V
Current requirement	0.6 A
Least count	0.001 mm

2. SURFACE ROUGHNESS TESTER

Model and make	Surftest, SJ-400, Mitutoyo
Measurement method	Stylus probe
Profile resolution	100 nm
Cut off length	0.8 mm
Tracing length	4.8 mm

3. DIGITAL GAUSS METER

Model and make	ESC18B, Eastwest Engineering Electronics Pvt. Ltd., India
Measurement range	2000 Gauss on $\times 1$ range 20000 Gauss on $\times 10$ range

4. OPTICAL EMISSION SPECTROMETER

Model and make	DV-6, Baird, USA
Base	Iron, Aluminium, Copper

Medium Argon gas

Accuracy 0.0001 %

3. MICROHARDNESS TESTER

Model and make MVH-2, Metatech, India

Software Used Quantimet

Load applied 1 Kg

Dwell time 20 s

