“OPTIMIZATION OF COMPOSITE TOOL ELECTRODE MATERIAL BY INVESTIGATING ELECTRODE WEAR FOR SS – 304 IN DIE-SINKING EDM”

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by

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CERTIFICATE

Certified that **Rekha Chandola** (Enrollment No. 1700101941) has carried out the research work presented in this thesis entitled "optimization of composite tool electrode material by investigating electrode wear for SS – 304 in die-sinking EDM**"** for the award of **Master of Technology** from Integral University, Lucknow under my supervision. The thesis embodies result of original work, and studies are carried out by the student herself and the contents of the thesis do not form the basis for the award of any degree to the candidate or to anybody else from this or any other university/Institution.

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ABSTRACT

In this project an attempt has been made to optimize the material of tool electrode in electrical discharge machining of stainless steel-304. In this project die- sink type EDM is used for experimental work. The controllable parameters used are discharge current, spark on time and spark off time and the resulting response will be tool erosion rate. The experiments were conducted using copper tungsten, beryllium copper and copper chromium zirconium alloy as tool electrodes.

Therefore, studying the electrode wear and related significant factors would be effective to enhance the machining productivity and process reliability. The experiments were carried out for 2 mm depth of cut with three pulse current settings of 5A, 10A and 15A by copper tungsten, copper chromium zirconium and beryllium copper electrode to investigate electrode wear rate as a performance factor.

In electrical discharge machine (EDM), improper selection of the electrode material may cause of poor machining rate or performance. This is due to material removal rate (MRR) characteristic. Less material removal rate (MRR) needs more time for machining process and become waste and not goods for production. The second problem is it will decrease the accuracy of the product because influence of the electrode wear ratio (EWR) characteristic.

During this investigation a comparative study has been carried out on electrical discharge machining of stainless steel -304 using different type of electrode viz. copper tungsten, copper chromium zirconium and beryllium copper. The process performances have been asserted by means of electrode wear rate.

AKNOWLEDGEMENTS

At this moment of accomplishment, I wish to pay my heartfelt gratitude and sincerest thanks homage to my guide, Dr. Shahnawaz Alam, department of mechanical engineering, Integral University Lucknow. This work would not have possible without his able guidance, support and encouragement. Under his guidance I have successfully overcome many difficulties and learned a lot. He used to review my thesis progress, give his valuable suggestions and made correction. His unflinching courage and conviction will always inspire me, and I hope to continue to work on his noble thought.

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ABBREVIATIONS

MRR	Material Removal Rate
EWR	Electrode Wear Rate
SR	Surface Roughness
DOC	Diametric Over Cut
T_{on}	Pulse on Time
T_{off}	Pulse off Time
EDM	Electrical Discharge Machining
Cu-W	Copper Tungsten
Cu-Cr-Zr	Copper Chromium Zirconium
Be-Cu	Beryllium Copper

CHAPTER – 1

INTRODUCTION

1.1 Electrical discharge machining

In recent years due to its brilliant technological properties, hard and difficult to machine materials, is extensively used in various sectors in modern manufacturing industries. Consequently, the machining of such material in an efficient manner is a challenge [1]. Electro Discharge Machining (EDM) is a brilliant option to this problem. It is generally used to machine difficult to-machine materials, 3-D complex structure, high strength, temperature resistant alloys. [2] Fig.1.1A shows the die-sinking electrical discharge machining process.

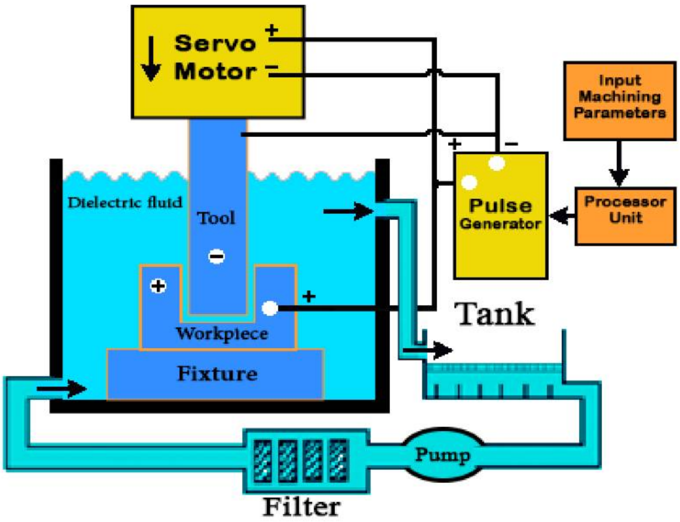


Fig. 1.1A Die-Sinking Electrical Discharge Machining

Electrical discharge machining (EDM) is the non-contact machining techniques have been continuously evolving in a mere tool and die making process to a micro-scale application machining. In recent years, EDM researchers have explored a number of ways to improve the sparking efficiency including some unique experimental concepts that depart from the EDM traditional sparking phenomenon to improve material removal rate [3]. The work piece and the electrode both evaporates at a very high intensity due to the discharge channel collapses immediately after the current is interrupted and deliver the liquid material into the dielectric fluid [4]. Craters occurs on the surfaces of the electrode and the work piece during this process [5], erosion occurs on the surface of work piece rapidly and new craters are developed next to the last crater [6]. The maximum amount of material removal with proper accuracy and the minimum damages of surface help the EDM more standardized process [7]. It can be obtained by the formation of different types of spark generators and production parameter optimization. Desired machining process performance is difficult to obtain because of the variation in the product and many number of variables [8].

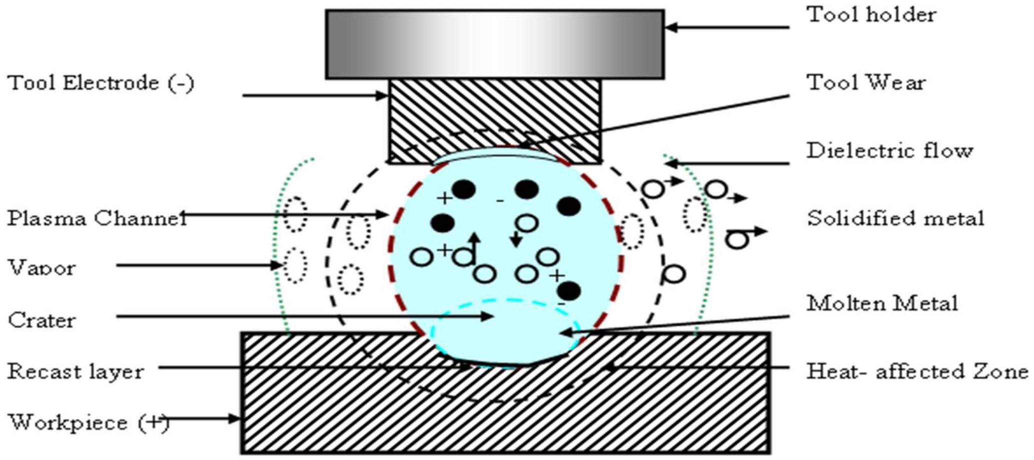


Fig. 1.1B Die-Sinking Electrical Discharge Machining

Electro discharge machining is known for its high statistic and non-linear nature and is therefore difficult to control. Furthermore, there does not exist a complete mathematical model for the physical varieties related to the removal process. Therefore, it is impossible to go through a classical identification procedure to find a transfer function permitting a controller design for stable process control. Consequently, EDM control requires multiple modules accomplished in hardware sensors and computer systems in combination with so-called technology tables. These technology tables that are created by the manufacturer contain users experience and deliver a great spectrum of basic machining parameters. Modern EDM plants contain so-called adaptive control optimization —which leads to on-line adjustment of an ensemble of working parameters [9]. A multi-response performance index is used to solve the electrical discharge machining process with multiple performance characteristics. The machining parameters (the work piece polarity, pulse-on time, duty factor, open discharge voltage, discharge current and dielectric fluid) are optimized with considerations of the multiple performance characteristics (electrode wear ratio and material removal rate) [10]. The capability of machining intricate features with high dimensional accuracy in hard and difficult-to- cut material has made electro discharge machining (EDM) process as an inevitable and one of the most popular nonconventional machining processes. In recent years, both EDM and micro-EDM processes are being used extensively in the field of mould making, production of dies, cavities and complex 3D structures using difficult-to-cut tungsten carbide and its composites. The objective of this paper is to provide a state of the art in the field of EDM and micro-EDM of tungsten carbide and its composites. The review begins with a brief introduction on the EDM and micro-EDM processes. [11] The gap between electrode and work piece is maintained in such a way that the impressed voltage is great enough to ionize the dielectric [12].

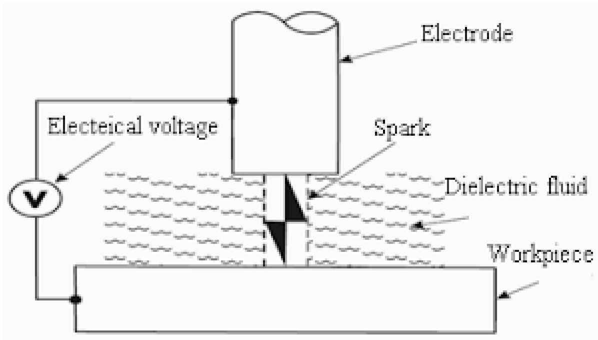


Fig. 1.1C Die-Sinking Electrical Discharge Machining

Electrical discharge machining (EDM) is one of the non-traditional machining processes, based on thermo electric energy between the work piece and an electrode. In this process, the material removal is occurred electro thermally by a series of successive discrete discharges between electrode and the work piece. The different parameters considered while carrying out the experiments on EDM would be the current, Ton, Toff, Time required, Depth of cut etc [13]. The main non-electrical parameters are the flushing of the dielectric fluid, work piece and electrode tool rotation. The EDM process needs a dielectric fluid medium that submerges both the electrode tool and the workpiece to at least a suitable distance above the gap between them. In addition to high dielectric strength, the dielectric fluid must have a flushing ability and fast recovery after breakdown. The dielectric fluid provides insulation against premature discharging, reduces the temperature in and around the machined area and cleans away the separated debris. For the die-sinking EDM, the dielectric fluid is a hydrocarbon and siliconebased dielectric oil and kerosene with an increased flash-point. Some die-sinking EDMs use de-ionized water for high-precision machining, such as fine hole drilling. De-ionized water and oil are also used with wire EDM. Many studies have recently been conducted to explore the use of oil-based synthetics to avoid harmful effects to the worker and the environment.[14]. In present time,various trends in electric discharge machining has been considered involving powder mixed electrolyte used for EDM, incorporating tool vibration, green EDM (dry EDM), treatment of electrode used for EDM, and validating EDM performance using modeling techniques. The tool wear mechanism and claimed that tool wear is affected by the precipitation of carbon from the hydrocarbon dielectric on the electrode surface during sparking. They also reported that the rapid wear on the electrode edge was due to the failure of carbon to precipitate at difficult-to-reach regions of the electrode tool [15]. Electrical discharge machining (EDM) process is one of the most commonly used non-traditional precise material removal processes. Electrical discharge machining (EDM) is a process for shaping hard metals and forming deep complex shaped holes by arc erosion in all kinds of electro conductive materials. Erosion pulse discharge occurs in a small gap between the work piece and the electrode. This removes the unwanted material from the parent metal through melting and vaporizing in presence of dielectric fluid. In recent years, EDM researchers have explored a number of ways to improve EDM Process parameters such as Electrical parameters, Non-Electrical Parameters, tool Electrode based parameters & Powder based parameters. Increase in peak current MRR, TWR and ROC increased significantly in a nonlinear fashion; MRR and ROC increased with the increase in pulse on time and gap voltage was observed to have some effect on their responses [16]. Input parameters such as current, pulse on time, voltage applied and the workpiece material greatly influences overcut. It increases with the increase of current but only up to a certain limit. It also depends on the gap voltage [17].

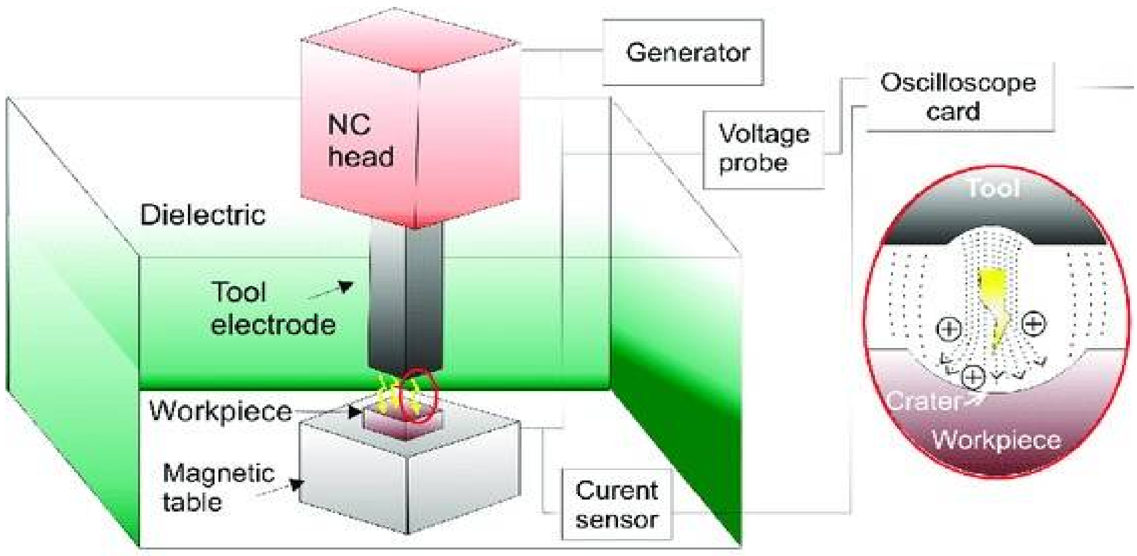


Fig. 1.1D Die-Sinking Electrical Discharge Machining

1.2 History of electrical discharge machining

The EDM process started first with the observations of Joseph Priestley in 1770's. He observed that electrical discharge plays a vital role in removal of material from the electrode. The process is also known as electro-discharge erosion. He noticed in his experiments that electrical discharges had removed material from the electrodes. During research to eliminate erosive effects on electrical contacts, the soviet scientists decided to exploit the destructive effect of an electrical discharge and develop a controlled method of metal machining. In 1943, soviet scientists announced the construction of the first spark erosion machining. The spark generator used in 1943, known as the Lazarenko circuit, has been employed for several years in power supplies for EDM machines and its form is used in many applications. The main aim of EDM is to improve the technology for increases in both the component precision and cutting speed. Lazarenko noticed in his experiments that electrical discharges had removed material from the electrodes. Although it was originally observed by Priestly, EDM was imprecise and riddled with failures. Commercially developed EDM techniques were transferred to a machine tool. This migration made EDM more widely available and a more appealing choice over traditional machining processes. Electrical Discharge Machining (EDM) is non-traditional, high precision metal removal process using thermal energy by generating a spark to erode the work piece. The work piece must be a conductive electricity material which is submerged into the dielectric fluid for better erosion. EDM machine has wide application in production of die cavity with large components, deep small diameter hole and various intricate holes. The EDM process was invented by two Russian scientists, Dr. B.R. Lazarenko and Dr.N.I. Lazarenko in 1943. The first numerically controlled EDM was invented by Makino in Japan. It is also used for finishing parts for aerospace and automotive industry and surgical components. In the middle of 1980s machining process on EDM were converted to a production instrument. Effective movement through EDM makes it more commonly offered and also engaging above outdated machining procedures. At starting days EDM process was actually inaccurate plus damaged using let-downs. Commercially established in the mid-1970s, the wire EDM machining originated to be a feasible practice that facilitated to run-through the metallic operational industry we have seen nowadays.

EDM has been substituting traditional machining operations. Now today EDM is a popular machining operation in several manufacturing productions all over the world’s countries. Most of the traditional machining process such as drilling, grinding and milling, etc. are failed to machine geometrically complex or difficult shape and size.

Those materials are easily machined by EDM non-traditional machining process which leads to broadly utilized as die in addition to mould assembly industries, making aeronautical parts and nuclear instruments at the minimum cost. Electric Discharge Machining has also established its presence touched on the different subject areas such as make use of sporting things, medicinal and clinical instruments as well as motorized research and development regions.

1.3 Classification of EDM

Electrical Discharge Machining can be classified into two ways-

1. Die-Sinking EDM
2. Wire cut EDM

1.3.1 Die-Sinking EDM

In the die-sinking EDM process, the work piece is machined by a controlled electrical spark generated in the gap between the electrode tool and the work piece. Sparking is repeated until the electrode tool shape is replicated in the work piece surface facing the electrode tool. The heat produced by the electrical spark causes a sharp temperature rise in the area to be machined (i.e.,8000 to12,000◦C). EDM machines contain a unit that controls and monitors the machining variables, such as the gap and axis movements. In this type of EDM Machining process, the two electrodes are fitted on their places on the machine parts which is work bench and tool holder. Both the electrodes should be electrically conductive. After that both the electrodes are immersed in an insulating liquid dielectric with the help of pump.

The dielectric is EDM oil/ kerosene / transformer oil. When the current is switched on, an electric tension is created between the two metal parts and if the two parts are brought together to within a fraction of an inch, the electrical tension is discharged and a spark jumps across. Where it strikes, the metal is heated up so much that it melts. In this period the discharge current is varied within range of 0.5 to 400 A, at 40-300 V applied voltage range and pulse duration can be varied from 2 to 2000 micro second. Different type of flushing method is applied to remove and prevent from accumulation of melted material from the work piece and smoothen the process. Fig.1.3A explains about the die- sinking EDM.

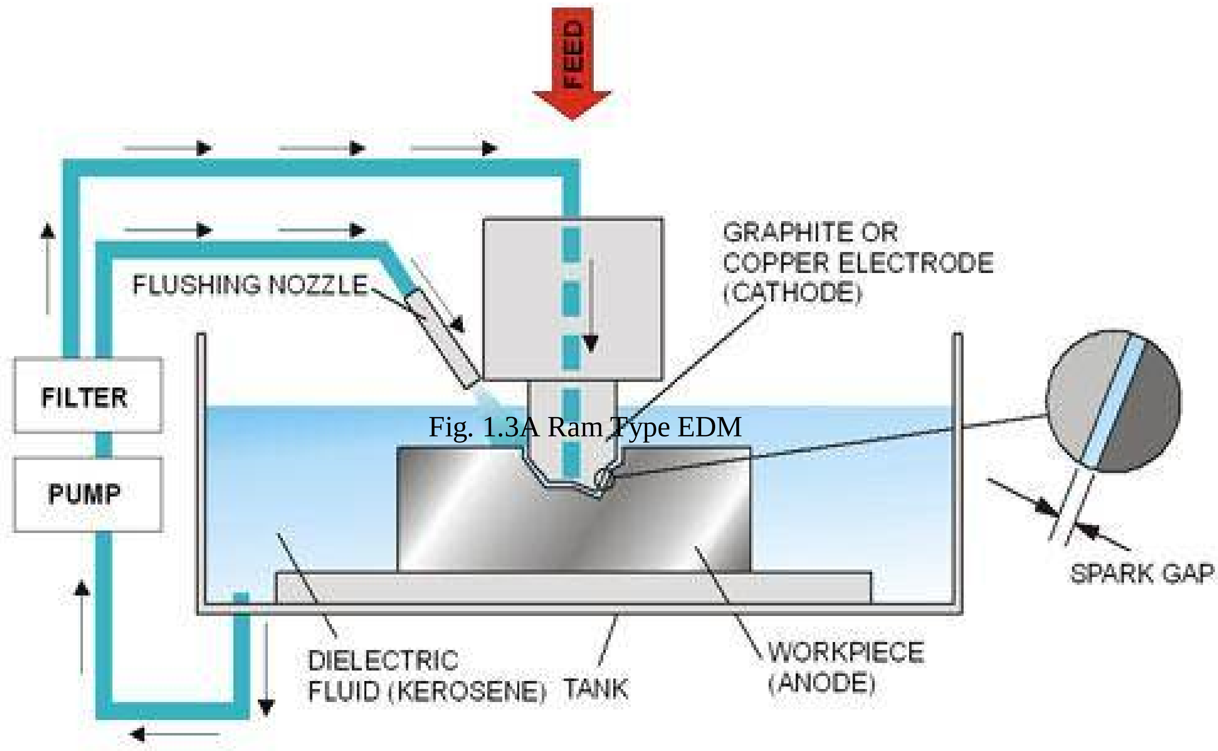


Fig. 1.3A Ram Type EDM

Fig. 1.3A Ram Type EDM

Sinker EDM is also called cavity type EDM or volume EDM. It consists of an electrode and the workpiece submerged in an insulating liquid such as oil or other dielectric fluids. The electrode and workpiece are connected to a suitable power supply. The power supply generates an electrical potential between the two parts. As the electrode approaches the workpiece, dielectric breakdown occurs in the fluid, forming a plasma channel, and a small spark jumps. These sparks usually strike one at a time. These sparks happen in huge numbers at seemingly random locations between the electrode and the workpiece. As the base metal is eroded, and the spark gap subsequently increased, the electrode is lowered automatically by the machine so that the process can continue uninterrupted. Several hundred thousand sparks occur per second, with the actual duty cycle carefully controlled by the setup parameters.

1.3.2 Wire-Cut EDM

In the wire EDM, a metallic thin wire is used to cut the workpiece along a well-defined path. Discrete sparks between the wire and the workpiece cause eroding in the machined area. The wire used is usually thin, the standard EDM wire is 0.25 mm. Micro-wires dimeter can range from 0.020 mm to 0.15 mm [18] and is normally copper, brass or coated steel materials. As with the die-sinking EDM, the wire and the workpiece do not have any contact during machining [19]. A high peak current of short duration is applied in this process. The machining variables and the movement of the worktable that holds the workpiece are controlled by the control units. Thus, complicated shapes can be produced using this process [20-25]. The control unit contains a microprocessor to maintain the gap between the wire and the workpiece in a suitable range, normally between 25 µm and 50 µm. In addition, the unit controls the feeding of the wire through the workpiece at a suitable speed that produces surfaces with very high accuracy [26-27]. The electrode wire is commonly made of brass or copper material. The diameter range of wire is 0.5 to 0.25 mm. The wire is wound on a two wire spool which is rotated in the same direction to strand the wire. The speed of wire movement is up to 3 m/min. It is utilizing CNC controlled machine set up to process the machining operation.

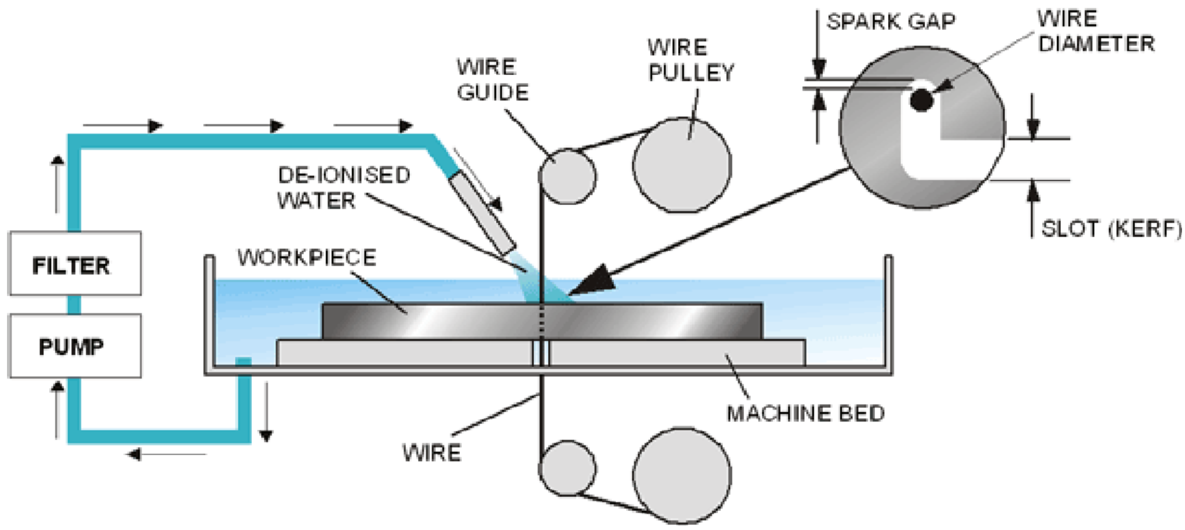


Fig. 1.3B WIRE-CUT EDM

Wire EDM Machining is also known as Spark EDM. Wire EDM also called electric discharge wire cutting process used for producing two or three dimensional complex shapes using an electro thermal mechanism for eroding the material from a thin single stranded by guide rulers metal wire surrounded by deionized water which is used to conduct electricity. Any hard material can cut by wire EDM process, but the material should have an electrical conductive property. It is an electro thermal production process in which a thin single-strand metal wire (usually brass) in conjunction with de-ionized water which is used to conduct electricity allows the wire to cut through metal by the use of heat from electrical sparks. Wire-cut EDM is typically used to cut plates as thick as 300mm and to make punches, tools, and dies from hard metals that are difficult to machine with other methods Wire-cutting EDM is commonly used where low residual stresses are desired, because it does not require high cutting forces for removal of material. If the energy/power per pulse is relatively low (as in finishing operations), little change in the mechanical properties of a material is expected due to these low residual stresses, although material that hasn't been stress-relieved can distort in the machining process.

Due to the inherent properties of the process, wire EDM can easily machine complex parts and precision components out of hard conductive materials.

1.4 Working principle

In this process the metal is removing from the work piece due to erosion case by rapidly recurring spark discharge taking place between the tool and work piece. A thin gap about 0.025mm is maintained between the tool and work piece by a servo system shown in fig 1. Both tool and work piece are submerged in a dielectric fluid Kerosene/EDM oil/de-ionized water is very common type of liquid dielectric although gaseous dielectrics are also used in certain cases. Basically, there are two different types of EDM: Die-sinking EDM & Wire-cut EDM. A EDM system has four major Components: (1) Computerized Numerical Control (CNC), (2) Power Supply, (3) Mechanical Section: Worktable, work stand, taper unit etc., (4) Dielectric System [28]

The material erosion mechanism primarily makes use of electrical energy and turns it into thermal energy through a series of discrete electrical discharges occurring between the electrode and work piece submerged in a dielectric liquid medium [29]. The thermal energy generates a channel of plasma between the cathode and anode [30] at a temperature in the range of 8000 to 12,000 °C [31]. Fig. 1.4Aexplains about the working principle of electrical discharge machining.

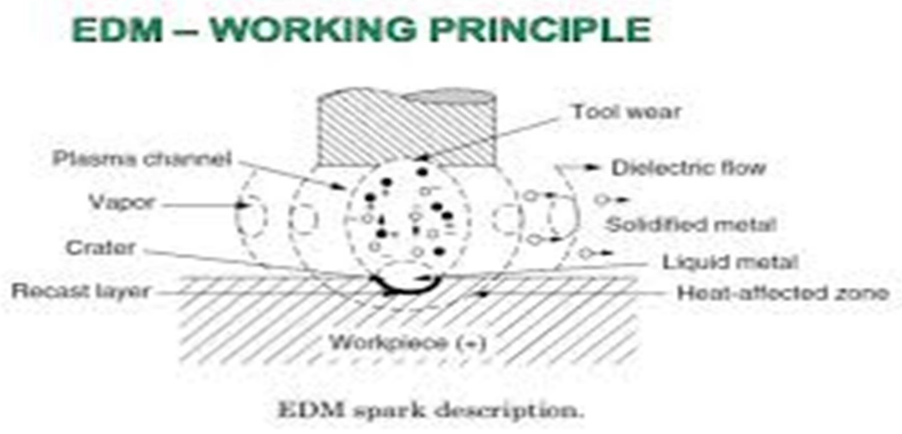


Fig. 1.4A Working Principle of Electrical Discharge Machining

When the pulsating direct current supply occurring at the rate of approximately 15,000–30,000Hz [32] is turned off, the plasma channel breaks down. Due to this sudden reduction in the temperature allowing the circulating dielectric fluid to implore the plasma channel and flush the molten material from the pole surfaces in the form of microscopic debris are observed.

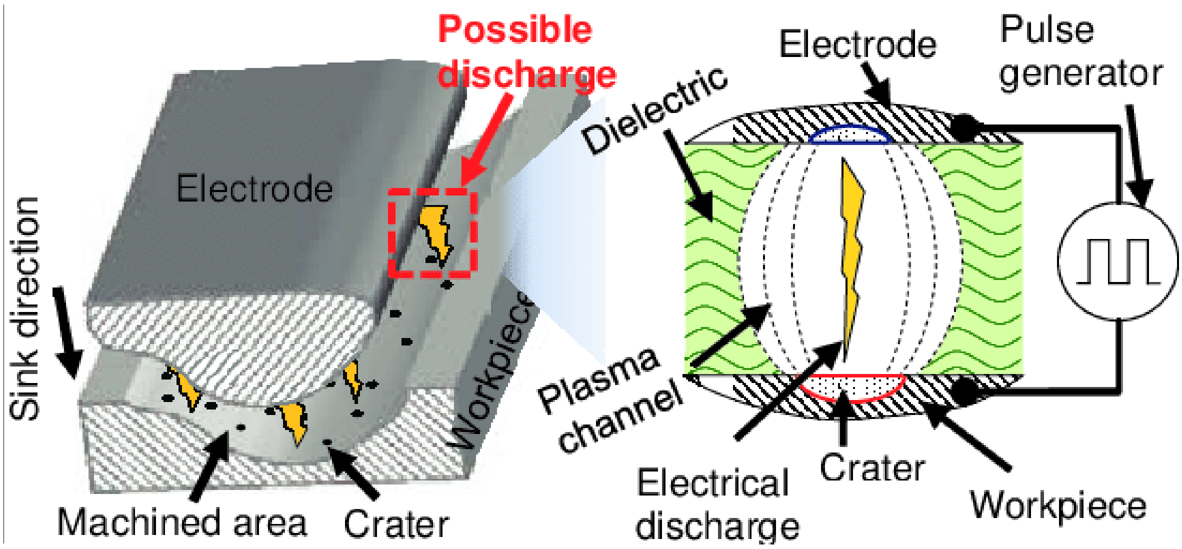


Fig. 1.4B Working Principle of Electrical Discharge Machining

The principle of EDM is to use the eroding effect of controlled electric spark discharges on the electrodes.It is thus a thermal erosion process. The sparks are created in a dielectric liquid, generally water or oil, between the work piece and an electrode,which can bec onsidered as the cutting tool.There is no mechanical contact between the electrodes during the whole process. Since erosion produced by electrical discharges, both electrode and work piece have to be electrically conductive. Thus, the machining process consists in successively removing small volumes of work piece material, molten orvaporized duringa discharge. The volume removed by a single spark is small.

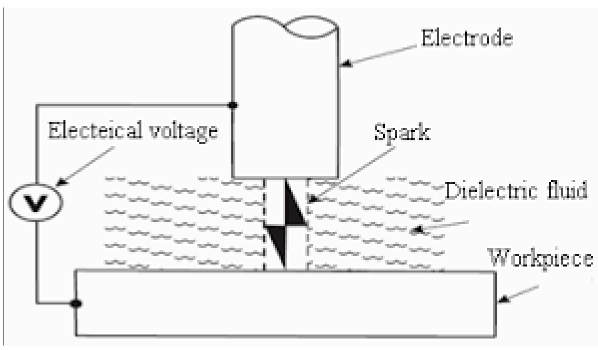


Fig. 1.4C Equipment setting of EDM

The principle of the EDM technique is to use thermoelectric energy to erode a workpiece by automatic spark repetition [33–36]. The rapidly recurring electrical discharges (sparks) between a non-contact electrode tool and the workpiece allow erosion caused by sparks generated between electrode tool and the workpiece surface [37]. In this process, both the workpiece and the electrode tool are submerged in an insulating dielectric fluid. The gap between the electrode tool and the workpiece is carefully selected so that the voltage across the gap has a value that can ionize the dielectric fluid in the gap due to electrical breakdown. Discrete electric discharges between the electrode tool and workpiece are produced which in turn generates a high temperature plasma channel, where instant thermal dissipation occurs. The local high temperature melts both workpiece and tool. Then, the eroded material solidifies in the form of debris. Flushing the dielectric fluid during the machining process carries away debris (separated solid particles) and restores the sparking condition in the gap and avoids short circuiting. No cutting forces exist between the electrode tool and the workpiece because there is no contact between them. This minimizes the vibration and stress problems that can occur during machining [38–41].

1.5 Material removal Mechanism

MRM is the process of transformation of material elements between the work-piece and electrode. These elements diffuse from the electrode to the work piece and vice versa, and are transported in solid, liquid or gaseous state, and then alloyed with the contacting surface by undergoing a solid, liquid or gaseous phase reaction [42].

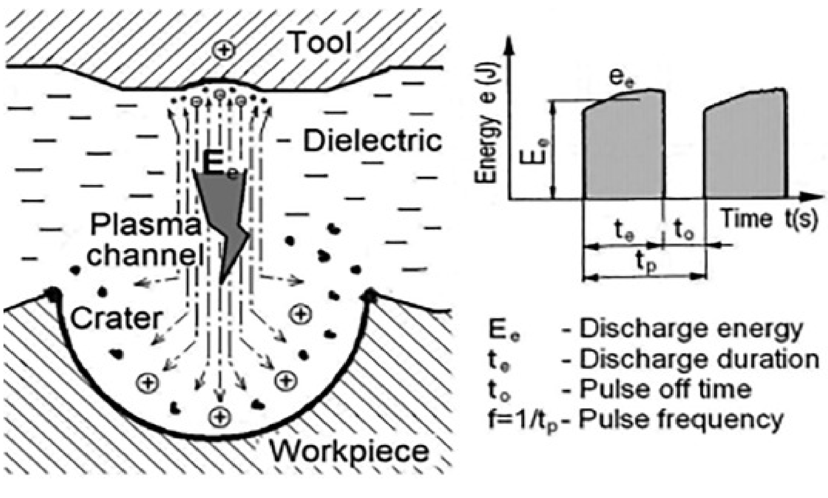


Fig. 1.5A Mechanism of MRR

Phase of sparking of MRM (breakdown, discharge and erosion) is highly influenced by the types of eroded electrode and work-piece elements together with disintegrated products of dielectric fluid. Mechanism behind material removal of EDM process is based on the conversion of electrical energy to thermal energy that categorized it to electro thermal process.

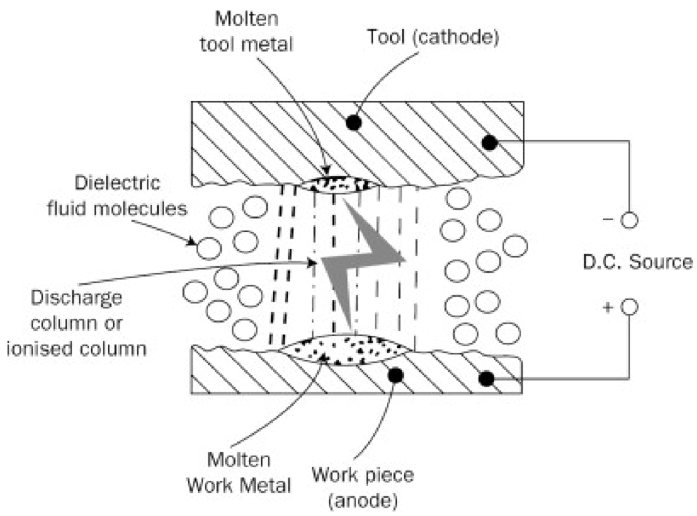


Fig. 1.5 B Mechanism of MRR

During machining both the surfaces may have present smooth and irregularities causes' minimum and maximum gap in between tool and work piece. At a given instant at minimum point suitable voltage is developed produces electrostatic field for emission of electrons from the cathode their electrons accelerated towards the anode. After getting velocity of electrons collides with the dielectric molecules breaking them into negative and positive ions. Because of that spark is generated with high temperature causes melting and vaporization of material from the workpiece as shown in figure and made the shape of tool on to the workpiece.

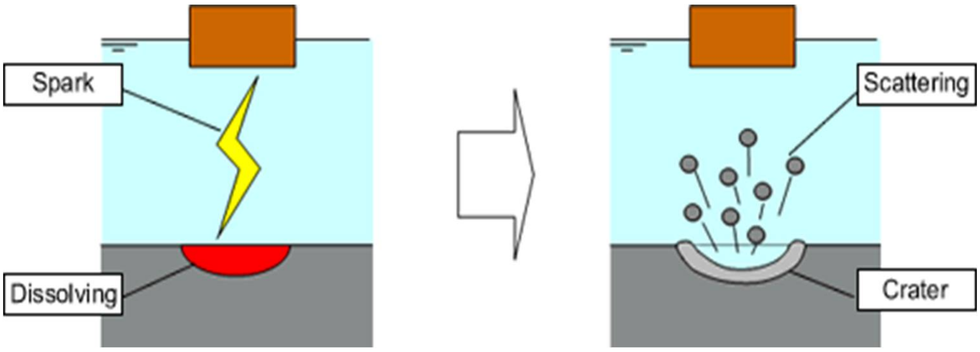


Fig. 1.5 C Mechanism of MRR

The erosive effect produced when spatial and discrete discharges occur between two electrically conductive materials. According to this theory, an electrical discharge between the tool electrode and the workpiece proceeds in four successive steps

1. **The ignition phase-**

   The elements of EDM are two electrodes, a cathode (−) and an anode (+), separated by a dielectric fluid. During operation, an open-circuit voltage is applied between them across a gap. At the beginning of the process, there is no current flux due to the resistance of the dielectric fluid. The servo control mechanism then advances the tool electrode in the direction of the workpiece, increasing the electric field between the pair of electrodes. At this time, a primary emission of the cathode's electrons occurs. This is called ignition phase.

2. **Formation of the plasma channel-**

   the positive ions originated from the dielectric collide with the cathode and liberate more electrons that are attracted to the anode, generating a secondary emission. This generates a superheating followed by a small evaporation of the dielectric, causing a reduction in the dielectric resistance and increasing the electrical current. At this time, the formation of a discharge tunnel can be observed and this causes a drop of the open-circuit voltage and a pronounced increase in the current. The plasma channel is then created. It is surrounded by a vapor bubble and the dielectric fluid that concentrates the discharge energy into a small volume. This plasma channel formation is also known as the voltage breakdown.

3. **Melting and evaporation of a small amount of the workpiece material-**

The generated plasma channel grows continually during the discharge duration. During this time, the high energy plasma melts both electrodes by thermal conduction, but limited electrode vaporization occurs, due to the high plasma pressure over the cathode and anode spots. The melting process can be explained as follows: The anode and cathode surfaces are affected, respectively, by the emission of electrons and positive ions. The electrons penetrate in the anode and transform their kinetic energy into thermal energy. The same occurs with the positive ions when they hit the cathode. It can be observed that the anode melts quicker than the cathode, due to lower mass of the electrons that collide with the anode compared to the positive ions.

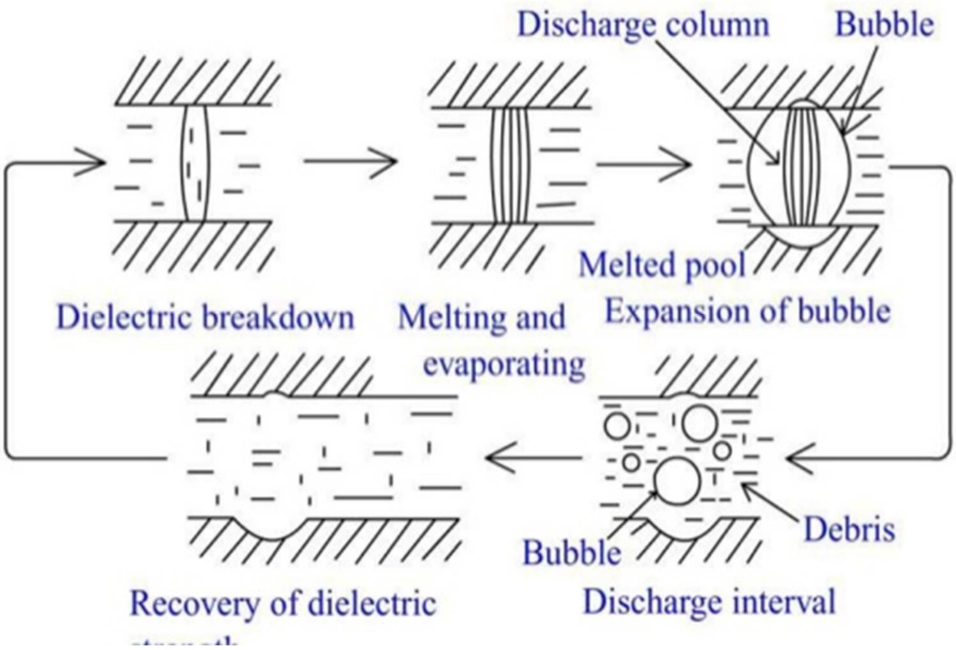


Fig. 1.5 D Mechanism of MRR

4. **Ejection of the liquid molten material-**

   At the end of the discharge duration, a pause period time begins, when the EDM machine stops the current abruptly. During this period, the plasma collapses and a vapor bubble is formed, causing the superheated, molten liquid on the surface of both electrodes to explode into the liquid dielectric. A part of the material is carried away by the dielectric, while another part resolidifies in the crater and in the surroundings, generating the so-called white layer or recast layer.

1.6 Electrode wear

Tool wear process is similar to Material removal mechanism as the tool and work-piece are considered as a set of electrodes in EDM. Electrode or tool wear is obtained from bombardment of either electron or positive ion. At positive electrode, the Electrode wear is developed due to bombardment of electrons. At negative electrode it is due to bombardment of positive ions. As negative and positive ions collide into electrode surface, heat is generated. The heat vaporizes the electrode material and a small amount of electrode material is removed with each spark. This removal of material is known as electrode wear.

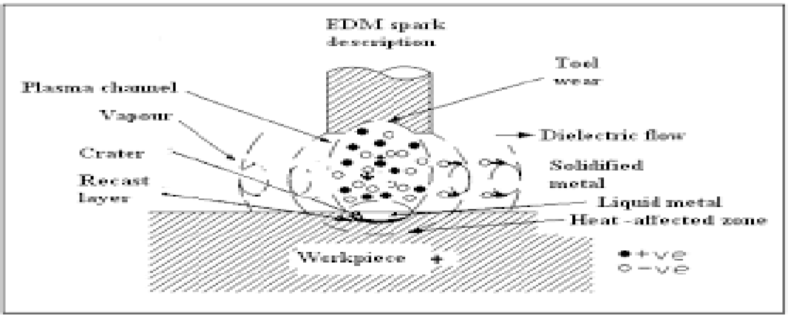


Fig. 1.6 A MECHANISM OF ELECTRODE WEAR

Electrode wear takes place during the EDM operation when the electrode (i.e. the tool) gets eroded due to sparking action. The rate at which the electrode wears is considerably less than that of the work material. EWR is the ratio of loss in weight of the electrode to the loss in weight of the workpiece, which is expressed as percentage. The reason for the reduction in EWR may be because of the coating of the carbon on the electrode. The heat generated during machining get diffuses to the spaces, and thereby decomposes carbon of the dielectric fluid at a very high temperature, part of which got deposited around the electrode preventing it from wearing further [43]. Another reason is that of the increase in MRR at such higher currents which reduces the wear ratio.

The electrode wear ratio (EWR) is define by the ratio of the electrode wear weight (EWW) to the work piece removal weight (WRW) and usually expressed as a percentage. Two measurements are necessary to fully define electrode wear:

1.6.1 End Wear

End wear is the percentage ratio of the amount of electrode material lost from the bottom end of the electrode, to the depth of the cavity burned. Fig.1.6A explains about the end wear of electrode.

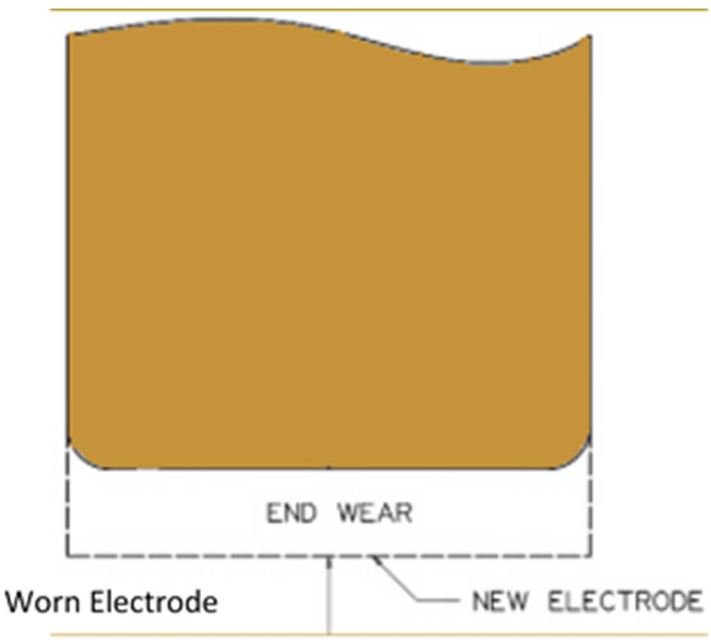


Fig. 1.6 B END WEAR

1.6.2 Corner Wear

Corner wear is the percentage ratio of the length lost (measured in the burn direction, usually Z) of a 90 degree external corner on the electrode, to the length of the corresponding sharp internal corner produced in the cavity. It should be noted that corner wear is almost always significantly greater than end wear, because the corner is being attacked by a multitude of sparks from many directions simultaneously. It should also be noted that corner wear is dramatically affected by the included angle of the electrode external sharp corner, since corner wear is a function of the surface-to-volume ratio of the corner condition.Fig.1.6B explains about the corner wear of electrode.

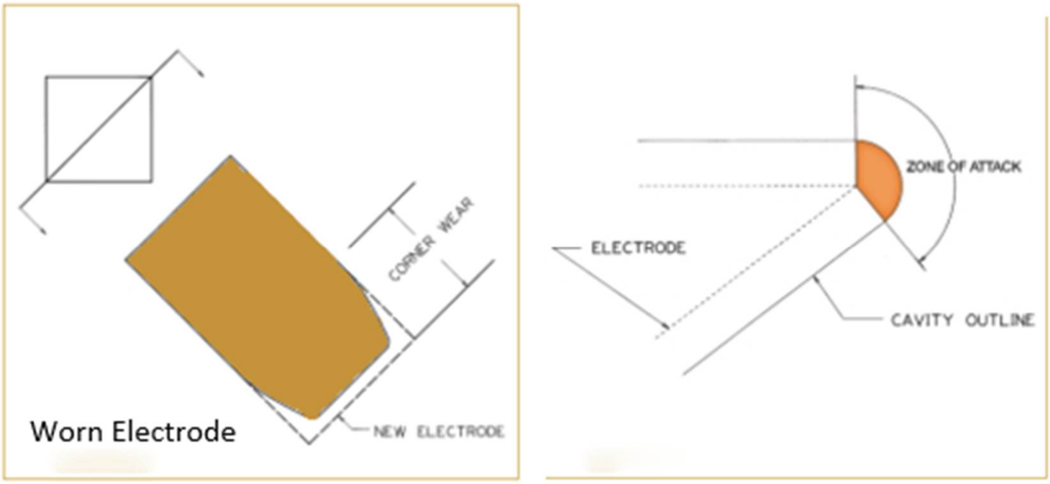


Fig. 1.6B CORNER WEAR

1.7 EDM Parameters

The EDM process is driven by both electrical and non-electrical parameters.

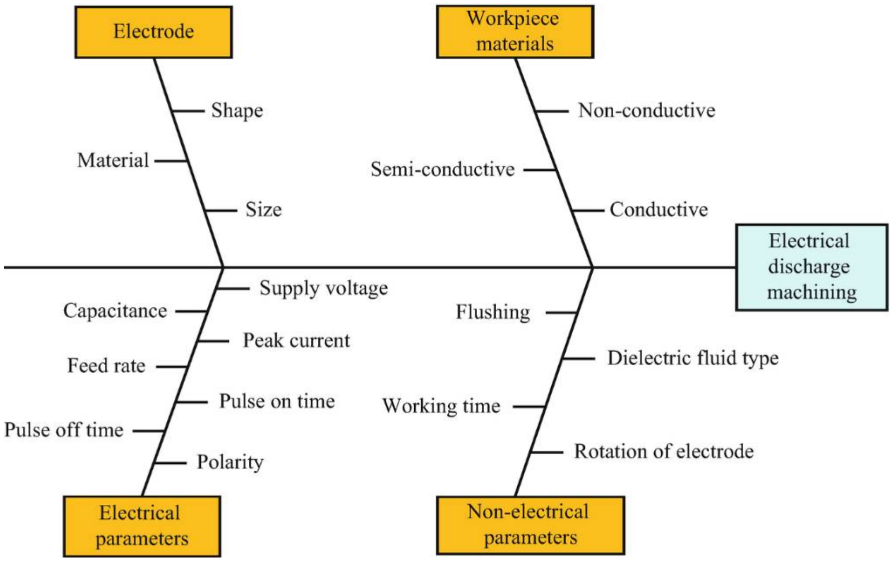


Fig. 1.7 EDM Parameters

The major electrical parameters are discharge voltage, peak current, pulse duration and interval, electrode tool gap, polarity and pulse waveform. The non-electrical parameters include rotation of the electrode tool, the flushing action of the dielectric fluid and the properties of The Process parameters can be divided into two categories i.e. electrical and non-electrical.

1.7.1 Electrical Parameters

a) Pulse Duration (Ton):

It is the duration of time measured in micro seconds. During this time period the current is allowed to through the electrode towards the work material within a short gap known as spark gap. Metal removal is directly proportional to the amount of energy applied during the on time period [44].Pulse duration is also known as pulse on time and the sparks are produced at certain frequency. Material removal rate depends on longer or shorter pulse on time period. Longer pulse duration improves removal rate of debris from the machined area which also effects on the wear behavior of electrode. As in EDM process erosion takes place in the form of melting and vaporization of both the tool and work material at the same time period, so with longer pulse duration more material has to be melt and vaporize. The substantial crater produced will be broader as comparison to the shorter pulse on time. But, in some experimental research work it has been proved that optimal pulse duration gives higher performance measures [45]. It conclude all that MRR cannot be increased by increasing the Pulse on time, a suitable combination of peak current is also needed for increasing rate of removing unwanted material from the work piece. At constant current and constant duty factor, the MRR is decreased with increase in pulse on time [46].

b) Pulse Interval (Toff):

This parameter is to affect the speed and the stability of the cut. If the off-time is too short, it improves MRR but it will because more sparks to be unstable in the machining zone. Kansal et al.[47] result out that increase in pulse interval time decreases the MRR. Saha et al.[48] reported out that for small value of pulse interval time period, the MRR was low, but with further increase MRR increases.MRR was dropped slowly with increase in pulse interval time. This is due to very short pulse interval the probability of arcing is larger because dielectric in the gap does not recover its dielectric strength.

c) Peak current

The peak current is basically a most important machining parameter in EDM. It is the amount of power used in EDM and measures in unit of amperage. During each pulse on-time, the current increases until it reaches a preset level, which is expressed as the peak current. In both die sinking and wire-EDM processes, the maximum amount of amperage is governed by the surface area of the cut. Higher amperage is used in roughing operations and in cavities or details with large surface areas. Higher currents will improve MRR, but at the cost of surface roughness and tool wear rate. All these factors are more important in EDM because the machined cavity is a mirror image of tool electrode and excessive wear will obstruct the accuracy of machining. New improved electrode materials, especially graphite, can work on high currents without much damage.

d) Discharge Voltage

Before current can flow, the open gap voltage increases until it has created an ionization path through the dielectric. Once the current starts to flow, voltage drops and stabilizes at the working gap level. The preset voltage determines the width of the spark gap between the leading edge of the electrode and workpiece. Higher voltage settings increase the gap, which improves the flushing conditions and helps to stabilize the cut. MRR, tool wear rate (TWR) and surface roughness increases, by increasing open circuit voltage, because electric field strength increases. However, the impact of changing open circuit voltage on surface hardness after machining has been found to be only marginal. Discharge voltage in EDM is related to the spark gap and breakdown strength of the dielectric.

e) Polarity

It may be positive or negative connected to tool electrode or work material. Polarity can affect processing speed, finish, wear and stability of the EDM operation. It has been proved that MRR is more when the tool electrodes are connected at positive polarity(+) than at negative terminal(-) .This may be due to transfer of energy during the charging process is more in this condition of machining. When an electrical discharge is generated electrons dispatch from the negative polarity collides with neutral molecules between the work piece and electrode which is responsible for ionization process in EDM. However, ionization is taken because the electron arrives at the positive terminal of the surface. The negative polarity is more desirable as compared to positive polarity [24]. It may be positive or negative connected to tool electrode or work material. Polarity can affect processing speed, finish, wear and stability of the EDM operation. It has been proved that MRR is more when the tool electrodes are connected at positive polarity(+) than at negative terminal(-) .This may be due to transfer of energy during the charging process is more in this condition of machining. When an electrical discharge is generated electrons dispatch from the negative polarity collides with neutral molecules between the work piece and electrode which is responsible for ionization process in EDM. However, ionization is taken because the electron arrives at the positive terminal of the surface. The negative polarity is more desirable as compared to positive polarity [50]. The polarity of the electrode can be either positive or negative. But the excess material is removed from side which is positive. When series discharge starts under the electrode area and passes through the gap, which creates high temperature causing material evaporation at the faces of both the electrode. The plasma channel is composed of ion and electron flows. As the electron processes (mass smaller than anions) show quicker reaction, the anode material is worn out predominantly. This effect causes minimum wear to the tool electrodes and becomes of importance under finishing operations with shorter pulse on-times. However, while running longer discharges, the early electron process predominance changes to positron process proportion of ion flow increases with pulse duration), resulting in high tool wear. In general, polarity is determined by experiments and is a matter of tool material, work material, current density and pulse length combinations. Modern power supplies insert an opposite polarity “swing pulse” at fixed intervals to prevent arcing. A typical ratio is 1 swing pulse for every 15 standard pulses.

f) Electrode GAP (Spark gap)

It is the distance between the electrode and the part during the process of EDM. An electromechanical and hydraulic systems are used to respond to average gap voltage. To obtain good performance and gap stability a suitable gap should be maintained. For the reaction speed, it must obtain a high speed so that it can respond to short circuits or even open gap circuits. Gap width is not measured directly, but can be inferred from the average gap voltage [49].

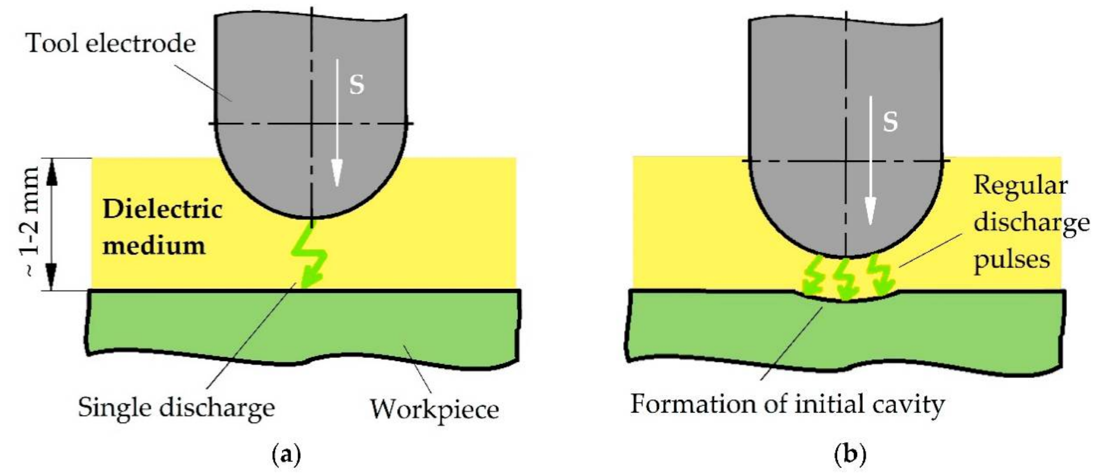


Fig. 1.7.1A Electrode GAP

The tool servo-mechanism is employed in EDM machine; its function is to control responsively the working gap to the set value. Mostly electro-mechanical (DC or stepper motors) and electrohydraulic systems are used, and are normally designed to respond to average gap voltage. Basic requirements for good performance are gap stability and the reaction speed of the system; the presence of backlash is particularly undesirable. The reaction speed must be high in order to respond to short circuits or open gap conditions. Gap width is not measurable directly, but can be inferred from the average gap voltage.

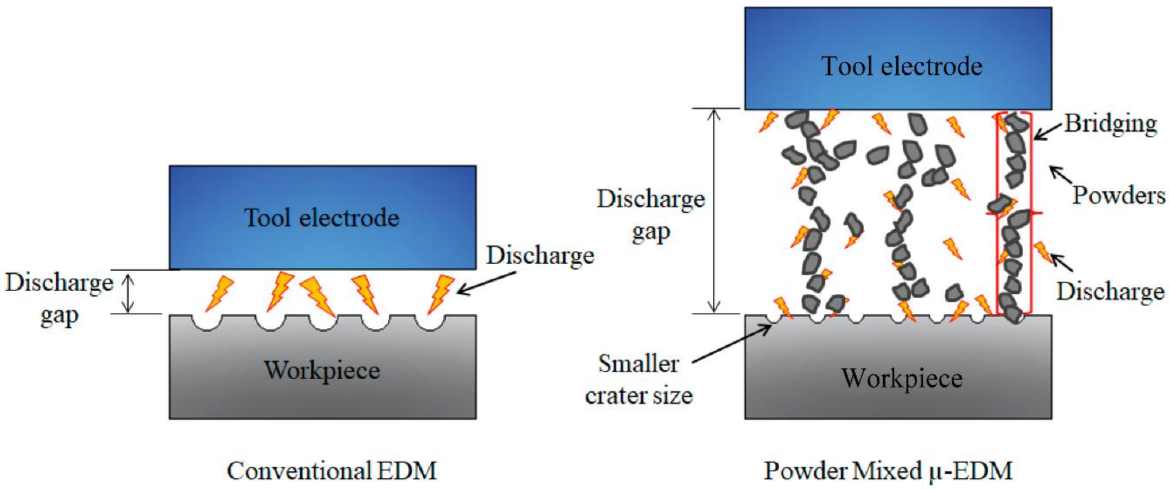


Fig. 1.7.1 B Electrode GAP

1.7.2 Non- Electrical Parameters

Non-electrical parameters such as the Rotational movement of electrode, flushing of dielectric fluid and aspect ratio (tool shape) together play a significant role in delivering optimal performance measures**.**

a) Dielectric Flushing

The dielectric fluid used in EDM have characteristics of high dielectric strength and quick recovery after breakdown, effective quenching and flushing ability, good degree of fluidity and easily available. TWR and MRR are affected by the type of dielectric and the method of its flushing. The different types of flushing are injection flushing, suction flushing, side flushing and flushing by dielectric pumping. Lonardo and Bruzzone exposed that flushing during the roughing operation affected the MRR and TWR, while in the finishing operation; it influenced the SR. The flushing rate also influences the crack density and recast layer, which can be minimized by obtaining an optimal flushing rate. In flushing most dielectric fluids are hydrocarbon compounds or water. Deionized water is used for wire-EDM and high precision die-sinking because of its low viscosity and carbon-free characteristics. The dielectric fluid is flushed through the spark gap to remove gaseous and solid debris during machining and to maintain the dielectric temperature by acting as coolant also. A control feature that is available on many machines to facilitate chip removal is vibration or cyclic reciprocation of the servo controlled tool electrode to create a hydraulic pumping action. Levy and Ferroni, also investigate hat Orbiting of the tool or workpiece has also been found to assist flushing and improve machining conditions.

b) Rotation of workpiece

In addition to the flushing of the dielectric, the techniques of applying rotational motion to the sparking process also affect the EDM performance. Guu and Hocheng provided a workpiece rotary motion to improve the circulation of the dielectric fluid in the spark gap and temperature distribution of the workpiece yielding improved MRR and SR. On the other hand, Kunieda and Masuzawa proposed a horizontal EDM (HEDM) process in which the main machining axis is horizontal instead of the conventional vertical axis. The change in the basic construction in addition to the rotary motion of the workpiece offered an accessible evacuation of debris improving the erosion efficiency and accuracy of the sparking process. HEDM has also been experimented in the micro-machining of small parts.

c) Rotation of Tool Electrode

Similarly, the performance measures of the EDM process also improves by the introduction of the rotary motion to the electrode. It serves as an effective gap flushing technique, which significantly improves the MRR and SR. The same alloying effect of migrating material elements from the workpiece and tool is also observed, in relation to the morphology, chemical composition and size distribution of debris, when using rotating electrodes. It was found that the vibratory motion yields comparable effects as the rotary motion of electrode improving the MRR, enhancing the surface quality of workpiece and increasing the stability of machining process.

d) Tool Geometry

Tool geometry is concerned with the shape of the tool electrodes.ie. Square, rectangle, cylindrical, circular.etc. The ratio of length /diameter of any shaped feature of material. In case of rotating disk electrode the ratio becomes thickness/diameter.

e) Tool Material (Electrode)

Engineering materials having higher thermal conductivity and melting point are used as a tool material for EDM process of machining . Copper, graphite, copper-tungsten, silver tungsten, copper graphite and brass are used as a tool material (electrode) in EDM. They all have good wear characteristics, better conductivity, and better sparking conditions for machining. Copper with 5% tellurium, added for better machining properties. Tungsten resist wear better than copper and brass .Brass ensures stable sparking conditions and is normally used for specialized applications such as drilling of small holes where the high electrode wear is acceptable (Metals Handbook, 1989). The factors that affect selection of electrode material include metal removal rate, wear resistance, desired surface finish, cost of electrode material manufacture and material and characteristics of work material to be machined.

1.8 EDM Parts

Electrical discharge machining unit consist of following components

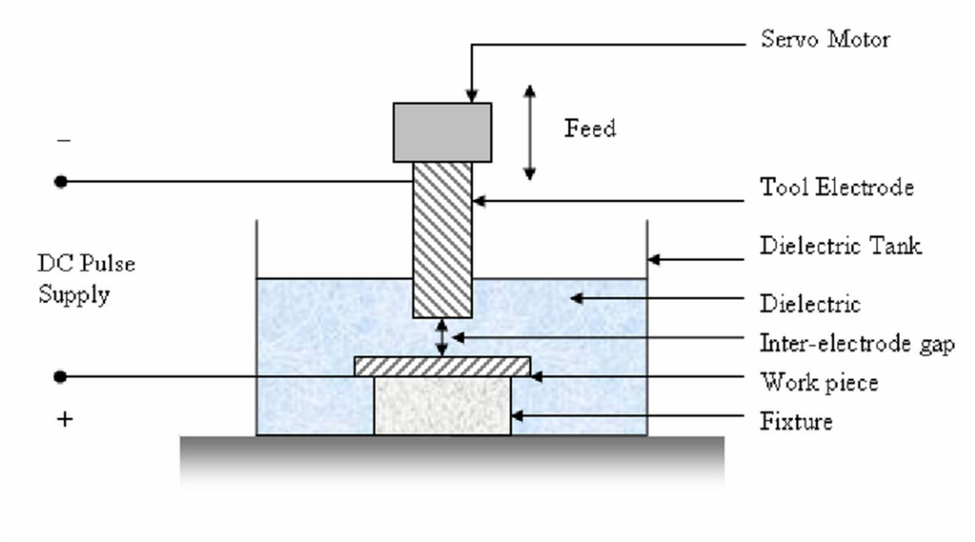


Fig. 1.8 EDM Parts

1.8.1 EDM Circuits

EDM Circuits helps to convert electrical energy into thermal energy and maintain the machining gap (known as spark gap) to generate succession of uniform electrical discharges in the form of sparks. The gap is filled with dielectric fluid. The spark discharge is initiated causing an oscillatory flow of current which reaches a maximum value shortly after the breakdown of the dielectric**.**

1.8.2 Dielectric Unit

The dielectric unit systems consist of dielectric tank, a pumping unit and a filtering unit to handle types of dielectric. Dielectric is often used when considering the effect of alternating electric fields on the substance. Mineral oil, kerosene and deionized water are generally used as a dielectric fluid in EDM .The Sinker EDM process uses dielectric acts as a medium through which controlled electrical discharge occurs. This dielectric also acts as a quenching medium to cool and solidify the gaseous EDM debris resulting from the discharge**.**

1.8.3 Servo feed control

Servo head is incorporated in EDM to maintain gap voltage since the dielectric parameters constantly fluctuate. Servo mechanism affecting the movement of the electrode may be either electric motor driven, solenoid operated or hydraulically operated or a combination of these. The servo feed control maintains the working gap at proper width**.**

1.9 ELECTRICAL DISCHARGE MACHINING APPLICATIONS

1. The EDM process is extensively used because of its many advantages over traditional Machining. It is also used in the manufacture of press tool and forging dies as well as molds making for injection moulding.
2. EDM has also successfully employed for producing intricate and irregular shaped profiles or outline common in tool rooms.
3. Small diameter holes in carbide or hardened steel can be machined by tube type electrodes of copper tungsten, using a micro machining attachment.
4. Internal threads and internal helical gears can be cut in hardened materials by using a Rotary spindle along with thread cutting.
5. Another field of application of EDM is in grinding process is similar to EDM except that The electrode is rotating wheel of graphite or brass.
6. EDM is advantageously adopted in grinding steel and carbide, thin and fragile sections, Brittle materials etc.
7. In travelling wire EDM has a wire guide and tensioning device to permit continuous Feeding of the expendable brass or copper wire electrode of diameter 0.2 mm or less.
8. Wire EDM well suited in the production of extrusion dies, blanking dies and punches.

1.9.1 Prototype Production

The EDM process is most widely used by themould-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.

1.9.2 Small Hole Drilling

The EDM process is also used in small hole drilling operation in many industrial applications. There is various profile of hole that can be formed with EDM process.

1.9.3 Coinage Die Making

For the creation of dies for producing jewelry and badges, or blanking and piercing (through use of a pancake die) by the coinage (stamping) process, the positive master may be made from sterling silver, since (with appropriate machine settings) the master is significantly eroded and is used only once. The resultant negative die is then hardened and used in a drop hammer to produce stamped flats from cut out sheet blanks of bronze, silver, or low proof gold alloy. For badges these flats may be further shaped to a curved surface by another die. This type of EDM is usually performed submerged in an oil-based dielectric.

1.10 Advantages of EDM

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

- Any material that is electrically conductive can be cut using the EDM process.
- Hardened work pieces can be machined eliminating the deformation caused by heat treatment.
- X, Y, and Z axes movements allow for the programming of complex profiles using simple electrodes.

- Complex dies sections and molds can be produced accurately, faster, and at lower costs.
- The EDM process is burr-free.
- Thin fragile sections such as webs or fins can be easily machined without deforming the part.
- Stock removal in spark machining is predominantly depends upon thermal characteristics of the workpiece material instead of mechanical properties.
- Complicated cutting profile, pointed and briery angles and internal junctions can be easily created.
- Machining of hardened material can be conducted without any distortion.
- Forces developed during machining operation are negligible
- In EDM process materials having electrical conductive property can be cut easily.
- With the help of CNC device systems on die sinking EDM machines, complex objects can be machined. Intricate dies and moulds can be shaped precisely, more rapidly, and at lesser costs.
- There are three axes movements, i.e. x, y, and z available to allow for the manufacturing of intricate profiles on the work piece.
- Case-hardened objects can be machined for removing the distortion caused by heat treatment process.
- Forces produced in the cutting process for material removal is negligible.
- Tinny stiff segments for example net or fins can be with no trouble machined without distorting the part.

1.11 Limitation of EDM

The limitations of EDM operation are as follows

(a) Both the material the tool and work piece material has to be electrical conductivity property. Because of this property creation of electric discharges is possible.

(b) Sometimes the wear rate on the electrode or tool is higher which requires use of more than one tool to finish the machining on the work piece.

(c) Sometimes the measurement of thin gap between the tool and work piece is not easily predictable especially in case of complex geometries which demands the flushing method to be differ from the simple one.

(d) Optimum machining settings of the EDM process largely be influenced by on the grouping of the tool and work piece. EDM manufacturers only fund these settings of the required material combination. Therefore, skill personnel required to develop his own technology.

(e) In case of die sinking EDM the cavity formed on the work piece with low metal removal rate. In case of wire-cut EDM only outline of the required shape on the work piece has to be machined. Therefore, EDM is limited to small production applications.

(f) Metal expulsion rate in as case of EDM is comparatively low. This process is applicable to electrically conductive materials only. The tool used should also be electrically conductive.

1.12.1 EDM Machine

In this experimental procedure ELECTROLUX EDM Machine (Model No. : D7130) is used for machining of workpiece. It has following technical specification:

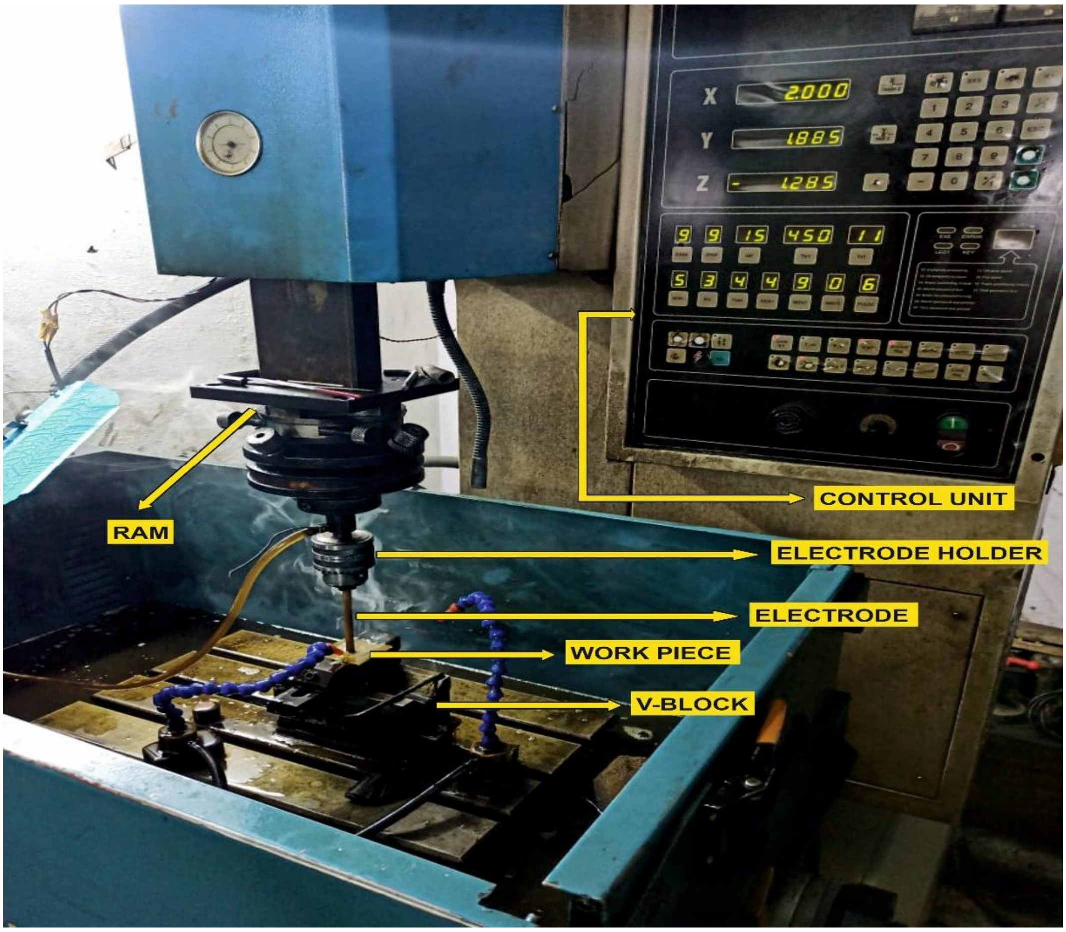


Fig. 1.12.1 EDM Machine

Table 1.12A Technical specification Electrolux EDM Machine

Specification	ZNC320
X,Y travel size (mm)	300×200
Working table size (mm)	500×300
Principal axis travel (mm)	200
Principal axis load (kg)	50
Max.workpiece weight (kg)	300
Chief axis connect board to working table (mm)	580
Work tank internal size (mm)	850×550×320
Overall weight (kg)	1200
Overall Dimensions (mm)	1400×1200×2100
Electric Cabinet Parameter and Specification	BH80AMP
Max.processing current (A)	80
Max.processing speed (mm/min)	500
Min Electrode Consumption	≤0.2%
Optimum roughness (um)	Ra<0.3
Max.power Consumption (kw)	7.5
Net weight (kg)	200
Overall dimensions (mm)	800×540×1700

1.12.2Workpiece Material

The work material used in this experiment is stainless steel 304. The chemical composition of the material is given in Table 1.12B**.** The rectangular work piece is 50 mm x 50 mm in dimensions and 3 mm in thickness. Electrical Discharge Machining will be done on this work piece. Fig.1.12A explains about the work piece of this experiment.

The work material chosen for this experimental work is SS 304 (stainless steel). The work piece is a rectangular bar of 150x25x2 mm3. The work piece is machined with surface grinding to ensure the uniform thickness.

Fig.1.12A WORK PIECE for Experiment

The work piece material used for the present investigation is AISI 304 stainless steel which is having a wide range of applications in the industrial field: Chemical, Pharmaceutical, Cryogenic, Food, Dairy, Paper industries etc.

In this experiment, AISI 304 stainless steel has been used as the work material and Cu electrode is used as the tool for the EDM process. Each work-piece material was of 25mm diameter and 10mm of width. Nine pieces of specified dimensioned work-pieces were prepared for the operation. The composition of AISI 304 stainless steel has given in table 1. In this experiment, paraffin based EDM oil was used.

The work piece material used for the present investigation is AISI 304 stainless steel which is having a wide range of applications in the industrial field: Chemical, Pharmaceutical, Cryogenic, Food, Dairy, Paper industries etc. The mechanical and physical properties of material are given in Table 1.12B

Table.1.12B Chemical Composition of Work Material

Property	Description	
Physical		
Density	8000 (Kg/m^3)	
Elastic Modulus	193MPa	
Thermal conductivity	16.2(W/m.K) at 100^{0}C	
	21.5(W/m.K) at 500^{0}C	
Electrical Resistivity	720 (nΩ.m)	
Specific Heat	500 (J/kg.K) from 0^{0}C-100^{0}C	
Mean Coefficient of Thermal Expansion	17.2 From 0^{0}C-100^{0}C	
	17.8 From 0^{0}C-315^{0}C	
	18.4 From 0^{0}C-538^{0}C	
Melting Point	1400-1450°C	
Mechanical	**Typical**	**Minimum**
Tensile Strength	600MPa	515MPa
Proof Strength, (off set 0.2%)	310MPa	205MPa
Elongation (Percent in 50mm)	60	40
Hardness (Brinell)	170	-
Hardness (Rockwell)	92	-
Endurance (fatigue Limit)	240MPa	-

1.12.3 Electrode Material

In this experiment Copper chromium zirconium alloy, Beryllium copper and Copper Tungsten are selected as electrode material.Fig.1.12C shows the tool electrode for electrical discharge machining.

Copper chromium zirconium

CuCrZr is a precipitation hardened alloy with additions of chrome and zirconium. The alloy has very high electrical and thermal conductivy at good strength levels. Furthermore CuCrZr offers outstanding relaxation and softening resistance. The properties make the alloy suited for complicated technical application where a high conductivy is demanded, and the component is exposed to stresses and temperatures. Fields of application are automotive, E-mobility, connectors and demanding applications in electrical engineering. CuCrZr is resistant to: Natural and industrial atmospheres as well as maritime air, drinking and service water, non-oxidizing acids, alkaline solutions and neutral saline solutions. CuCrZr is not resistant to:

Ammonia, halogenide, cyanide and hydrogen sulfide solutions and atmospheres, oxidizing acids and sea water

Fig. 1.12.3A EDM Electrode- Copper chromium zirconium

Applications:

Zirconium addition to chromium copper improves creep resistance at high operating temperatures and reportedly reduces sticking of electrodes to the work during spot welding of galvanized materials.

Popular as moulds and dies for continuous casting due to its excellent electrical and thermal conductivity, hardness and ease of fabrication

Low toxicity with excellent mechanical wear resistance and high radiation resistance

Used extensively as electrodes in resistance welding and as circuit breakers in the electrical sector and also as rod extensions for seam and spot welding.

Beryllium copper

Beryllium copper is known by its high fatigue strength, excellent wear and corrosion resistance and non-magnetic material. And it finds application in electronic and electro-mechanical devices. Beryllium copper alloy which displays very high mechanical properties with a reasonably good electrical and thermal conductivity. Beryllium copper is a ductile, weldable, and machinable alloy. Like pure copper, it is resistant to non-oxidizing acids like hydrochloric acid and carbonic acid, to plastic decomposition products, to abrasive wear, and to galling. It can be heat-treated for increased strength, durability, and electrical conductivity. Beryllium copper attains the greatest strength (to 1,400 MPa (200,000 psi)) of any copper-based alloy. It has good thermal conductivity 3-5 times more than Tool steel.

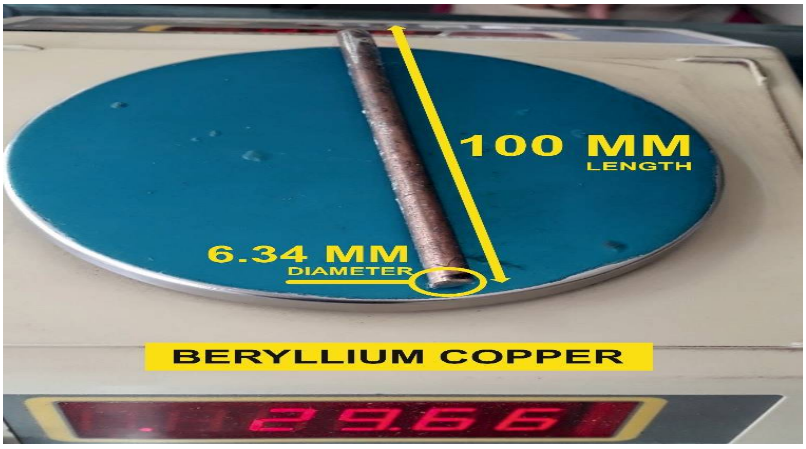


Fig. 1.12.3B EDM Electrode- Beryllium Copper

Copper–tungsten (CuW)

Copper–tungsten electrode was designed in order to combine the best properties of copper (high electrical and thermal conductivities) and tungsten (high melting point), achieving a low wear electrode. CuW electrode is manufactured by powder metallurgy techniques, pressing both materials in a mold and then sintering them. During sintering, shrinkage occurs and porosity should be controlled. Copper–tungsten materials are generally found in a 25–30%Cu 75–70%W grade. Table 1.12C shows the properties of a typical CuW electrode, with 25%Cu 75%W.

Table.1.12C Chemical Composition of copper tungsten Material

Material	CuW
Density (g/cm^3)	14.84
Electrical resistivity ($\mu\Omega$ cm)	3.83
Thermal conductivity (W/mK)	220
Linear expansion coefficient ($\times 10^{-6}$/K)	10.77
Melting point (°C)	1085–3410
Specific heat (J/kg K)	214

Fig. 1.12.3C EDM Electrode- Copper Tungsten

Observing the table one can see that the presence of tungsten diminishes the electrical and thermal conductivity of the material when only copper is used, which reduces the machining speed. On the other side, the tungsten greatly enhances the melting point of the electrode, leading to a consequent lower wear.

1.12 Objective of project

In this project an attempt has been made to optimize the material of tool electrode in electrical discharge machining of stainless steel-304. In this project die- sink type EDM is used for experimental work. The controllable parameters used are discharge current, spark on time and spark off time and the resulting responses are work piece erosion rate and tool erosion rate. The experiments were conducted using copper tungsten, beryllium copper and copper chromium zirconium alloy as tool electrodes.

In electrical discharge machine (EDM), improper selection of the electrode material may cause of poor machining rate or performance. This is due to material removal rate (MRR) characteristic. Less material removal rate (MRR) needs more time for machining process and become waste and not goods for production. The second problem is it will decrease the accuracy of the product because influence of the electrode wear ratio (EWR) characteristic.

During this investigation a comparative study has been carried out on electrical discharge machining of stainless steel -304 using different type of electrode viz. copper tungsten, copper chromium zirconium and beryllium copper. the process performances have been asserted by means of electrode wear rate.

Therefore, studying the electrode wear and related significant factors would be effective to enhance the machining productivity and process reliability. The experiments were carried out for 2 mm depth of cut with three pulse current settings of 5A, 10A and 15A by copper tungsten, copper chromium zirconium and beryllium copper electrode to investigate material removal rate and electrode wear rate as a performance factor.

Although various parameters could be considered for electrical discharge machining process, but in the present work, three process parameters namely discharge current, pulse-on time, and pulse-off time are considered. To find out the optimal composite material for tool electrode in Die –sinker EDM for machining of stainless steel – 304

CHAPTER – 2

LITERATURE REVIEW

In this chapter, some research papers regarding Current Research Trends in Electrical Discharge Machining have been discussed. Review is mainly releated with the EDM parameters such as current, voltage, pulse on time, duty cycle, etc. and how these affect the machining characteristics like MRR, SR, OC, etc

Survey of literature indicates that Electrical discharge machining (EDM) is one of the earliest non-traditional machining processes, based on thermoelectric energy between the workpiece and an electrode. In this process, the material is removed electro thermally by a series of successive discrete discharges between two electrically conductive objects, i.e., the electrode and the workpiece. The performance of the process, to a large extent, depends on the material, design and manufacturing method of the electrodes.

Nikhil Kumar, Lalit Kumar et al [50] (2012), Comparative study for MRR on Die-sinking EDM using electrode of copper & graphite. In their research Die-sinker EDM using copper and graphite electrode experiment has been done for optimizing Performance parameters and reducing cost of manufacturing, finally it is found that a silver electrode give better performance in certain characteristics but the cost become high for machining so keeping in mind cost and other some characteristics a graphite electrode is more suitable than copper electrode in case of both MRR and TWR

A Thillaivanan, P.Asokan et al [51] (2010), Optimization of operating parameters for EDM process based on the Taguchi Method and Artificial Neutral Network. In this paper the complexity of electrical discharge machining process which is very difficult to determine optimal cutting parameters for improving cutting performance has been reported. Optimization of operating parameters is an important step in machining, particularly for operating unconventional machining procedure like EDM.

Anjali V. Kulkarni et al [52] (2007), Synchronized study of the process revealed that the discharge temperature rise is due to the bombardment of the electrons generated during the the discharge process. At times, the temperature rise at the discharge-affected zone is of the order of the boiling temperature of work piece material. Machining, and hence, the material removal takes place.

M. Durairaj et al [53] (2013), Analysis of Process Parameters in EDM with Stainless Steel using Single Objective Taguchi Method and Multi Objective Grey Relational Grade. This paper summarizes the Grey relational theory and Taguchi optimization technique, in order to optimize the cutting parameters in EDM for SS304. The objective of optimization is to attain the minimum kerf width and the best surface quality simultaneously and separately.

Raghuram S. et al [54] (2013), Optimization of EDM parameters using Taguchi Method for Steel IS 2026. This paper aims to investigate the optimal set of process parameters such as current, pulse ON and pulse OFF time in Electrical Discharge Machining (EDM) process to identify the variations in three performance characteristics such as rate of material removal, wear rate on tool and surface roughness value on the work material for machining Mild steel using copper electrode

M.A. Ali et al [55] (2013), The effect of EDM Die-sinking parameters on Material Removal Rate of Beryllium Copper was studied. The appropriate parameters were selected to study the influence of operating parameters on MRR. It was found that peak current was the most significant factor affecting the MRR.

Ghoreishi and Atkinson [56] explained that material removal rate, electrode wear rate and surface finish is affected by rotation and vibration of tool electrode in die sinking EDM with flat electrode. It is investigated that the combination of ultrasonic vibration and electrode rotation leads to increase in MRR and TWR. The vibro-rotary increases MRR by up to 35% compared with vibration EDM and by up to 100% compared with rotary EDM in semi finishing.

B.S. Reddy et al. [57] optimized EDM parameters over surface roughness, hardness, electrode wear and material removal rate. Mixed factorial design of experiments and multiple regression analysis techniques had been employed to achieve the desired results. The parameters in the decreasing order of importance for; MRR: servo, duty cycle, current and voltage; TWR: current, servo and duty cycle; SR: current; HRB: servo only.

M.M. Rahman et al. [58] explained the relation of the peak current and pulse duration on the EDM performance characteristics. The conclusions drawn were: the current and pulse on time affected the MRR, TWR and SR. The MRR increases almost linearly with the increasing current, the SR increases linearly with current for different pulse on time, TWR increased with increasing peak current while decreased when the pulse on time was increased.

Iqbal and Khan [59] explained that the voltage and rotational speed of the electrode are the two significant parameters for EDM milling. Optimization is concerned with maximizing the MRR and minimizing EWR along with an optimum surface roughness.

Singh and Maheshwari [60] investigated that the input parameters such as current, pulse on time, voltage applied and the workpiece material greatly influences overcut. It increases with the increase of current but only up to a certain limit. It also depends on the gap voltage.

S Dhar et al. [61] concluded that with increase in peak current MRR, TWR and ROC increased significantly in a nonlinear fashion; MRR and ROC increased with the increase in pulse on time and gap voltage was observed to have some effect on the three responses.

Drozda [62] explained that the tool electrode is responsible to transport the electrical current to the workpiece. Therefore, any material to be used as a tool electrode is required to conduct electricity. Since EDM is a thermal process, it would be logical to assume that the higher the melting point of the material of electrode, the better the wear ratio will be between electrode and workpiece.

Jeswani [63] have investigated that the electrode wear with the help of dimensional analysis. An empirical relation was developed relating the material eroded from tool electrode to the energy pulse, density, thermal conductivity, specific heat and latent heat of vaporization of electrode material.

Crookall et al. [64] have optimized the effect of debris concentration on erosion rate. They have reported that as debris increases erosion of material also increases. Also use of distilled water as dielectric results in lower erosion rates in comparison to kerosene as dielectric

Mohri et al. [65] have explained the tool wear mechanism and claimed that tool wear is affected by the precipitation of carbon from the hydrocarbon dielectric on the electrode surface during sparking. They also reported that the rapid wear on the electrode edge was due to the failure of carbon to precipitate at difficult-to-reach regions of the electrode tool

Puertas et al. [66] investigated that the intensity and pulse time factor were the most important in case of surface roughness while the duty cycle factor during machining was not significant. The intensity factor was again influential in case of TWR. The important factors in case of MRR were the intensity followed by duty cycle and the pulse time.

Saha [67] has explained the material removal by erosion process for similar and dissimilar material. It was found that the distribution of energy per pulse between the electrodes, dielectric and plasma and hence their erosion rates depends on electrode material pair and their polarity.

Alpesh M. Patel et al [68] (2013), explained that operating parameters is an important step in machining, particularly for operating unconventional machining procedure like Wire cut Electro Discharge Machining. Since wire-cut EDM has experienced explosive growth in application users demand and need maximum productivity and through-put, increased accuracy, and predictable performance

Sanjay Kumar Majhi et al [69] (2013), optimized the approach for the determination of the optimal process parameters which maximize the material removal rate and minimize surface roughness & the tool wear rate. The input parameters of electrical discharge machining considered for this analysis are current, pulse duration and pulse off time. The influences of these parameters have been optimised by multi response analysis.

Ashok Kumar et al [70] (2007), have conducted experimental procedure and investigated the Machine parameters for EDM using U shaped electrode using Taguchi experiment. Where diameter of U-shaped electrode, current and pulse on time are taken as process input parameters and material removal rate, tool wear rate overcut on surface of work piece are taken as output parameters.

Ajeet Bergaley, Narendra Sharma et al [71] (2013), investigation of Electrical and Non Electrical factors in EDM for machining Die steel using copper electrode by adopting Taguchi Technique. This paper presents a work on the performance parameter optimization for material removal rate (MRR) and electrode wear rate (EWR).

Nanimina et. al. [72] studied the effects of EDM on Al6061- 30%Al2 O3 .Metal matrix composites. They selected peak current, pulse on time and pulse off time as machining parameter and material removal rate and tool wear rate as responses. They found the High current and pulse on time increase the material removal rate. More tool wears are observed at low peak current and pulse on time.

Raj Mohan et. al. [73] investigated the influence of process parameters and their interactions viz., voltage, pulse on time, current and pulse off time on the material removal rate (MRR) in stainless steel (304) as workpiece. Signal to noise ratio (S/N) and analysis of variance (ANOVA) was used to analyze the effect of the parameters on MRR and Taguchi method used to find the optimum cutting parameters. It was concluded that the two main significant factors that affects the MRR are pulse current and pulse on time.

Herpreet Singh et. al. [74] studied the influence of operating parameters like pulse-on-time and pulse-off-time for responses such as Metal removal rate (MRR) and Tool Wear Ratio (TWR) on the EDM using steel as workpice and cryogenic and noncryogenic electrode of copper material. The cryogenic treatment is used for increasing the material removal rate and lowering the tool wear rate. It was found that with increase in pulse on time tool wear rate is decreased in both electrode cryogenic treated and non - cryogenic copper electrode. Tool wear rate is increased with increase in pulse off time.

Nikalje et. al. [75] studied the influence of process parameters such as discharge current, pulse-on-time and pulse-off-time for process performance criteria such as MRR, Tool Wear Ratio (TWR), Relative Wear Ratio (RWR) and surface roughness. The MDN 300 steel was used as workpiece material and copper as electrode.

Manabhanjan Sahooet. al. [76] studied the influence of process parameters such as discharge current, pulse-on-time and duty cycle for process performance criteria such as metal removal rate (MRR) and electrode wear rate (EWR). Experiments are conducted on tungsten carbide with copper electrode in a die sinking EDM.

Verma et. al. [77] studied the effect of EDM of process parameters on titanium alloy. For this purpose die-sinking EDM was used and for optimization full factorial technique was used. The input parameters were peak current, gap voltage, pulse on time and dielectric fluid pressure. Material removal rate and surface roughness were taken as response parameters

Tomadi et al. [78] (2009) investigated that impact from claiming machining settings for tungsten carbide on the outputs for example, TWR, MRR and surface complete. Affirmation test performed on assess slip the middle of predicted values and Eventually Tom's perusing test runs as far as machining aspects. They were discovered crazy copper tungsten apparatus utilize for preferred surface completing of the worth of effort bit. They were utilizing full factorial doe to streamlining Furthermore discovered out for more stupendous pulse off time lesseps device around wear about tungsten carbide Also for current, voltage and pulse on time augment device wear expanded.

From the literature survey, it can be observed that many studies were carried out to investigate the optimal set of process parameters such as Voltage, Current and Pulse on time in the electric discharge machining to identify the variations in the three characteristics such as Material removal rate (MRR), Tool wear rate (TWR), and Surface roughness (Ra) on the work piece. There is not much published work on composite EDM electrode material and their effect on tool electrode wear. Use of new materials like composite material which has low tool wear rate, high corrosion resistance and reasonably good conductivity has not been sufficiently investigated. Like material removal mechanism, electrode wear mechanism (ERM) is also a complex phenomenon. Simplified assumptions and approaches in theoretical modelling, have led to large disagreement with results. In this work, an experimental study is carried out for the simultaneous optimization of electrode wear and to study the effects of machining parameters. The study is carried out while machining SS304 material in Electrical Discharge machining (EDM) using three electrode materials copper tungsten, copper chromium zirconium and beryllium copper.

CHAPTER – 3

DESIGN OF EXPERIMENT & EXPERIMENTAL WORK

3.1 Design Matrix

The matrix is developed by using pulse current level and electrode material as an input parameter for obtaining material removal rate of work piece as well as electrode wear rate of electrode material. The experiments are carried out for 2 mm depth of cut. In this experiments three pulse current settings of 5A, 10A and 15A is used with the application of copper tungsten, copper chromium zirconium and beryllium copper electrode.

Table 3.1 Matrix prepared for input parameters and respective performance measure factor

S.NO.	**INPUT PARAMETER**			**PERFORMANCE MEASURE FACTOR**
	ELECTRODE MATERIAL	**Pulse Current (Amp)**	**T_{on}/T_{of}**	**ELECTRODE WEAR RATE**
1	Beryllium Copper	5	450/11	- -
2	Beryllium Copper	10	450/11	- -
3	Beryllium Copper	15	450/11	- -
4	Copper Chromium Zirconium	5	450/11	- -
5	Copper Chromium Zirconium	10	450/11	- -

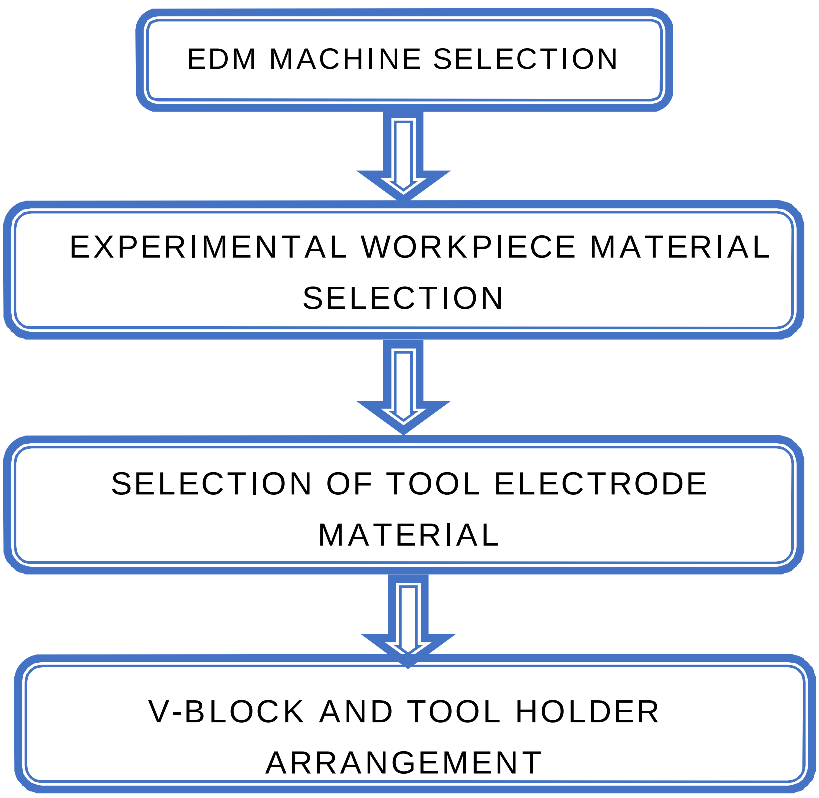
6	Copper Chromium Zirconium	15	450/11	- -
7	Copper Tungsten	5	450/11	- -
8	Copper Tungsten	10	450/11	- -
9	Copper Tungsten	15	450/11	- -

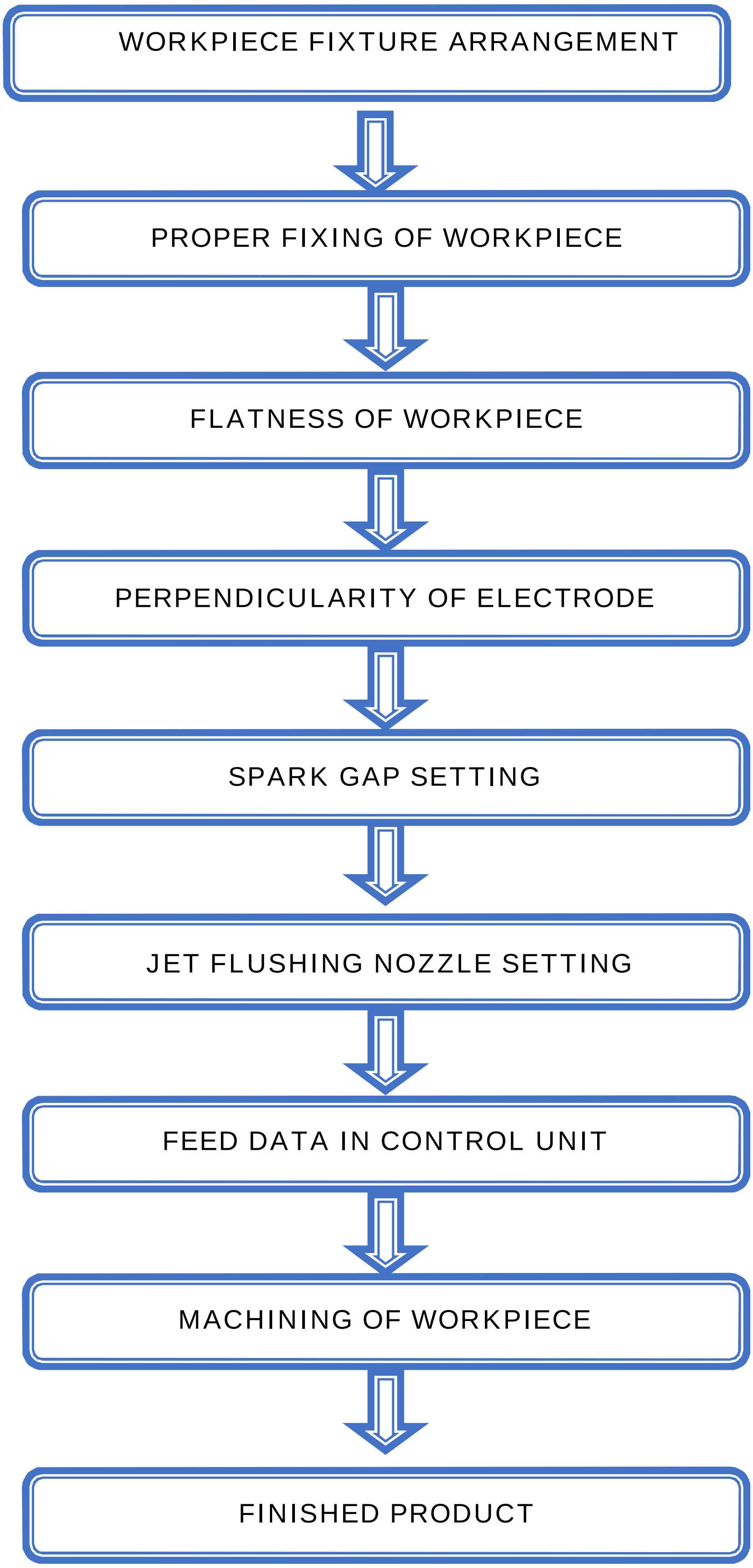
Where pulse current in Ampere

EWR i.e. electrode wear rate in gram/min

3.2 Experimental work

Steps of experiment: In order to run the experiment successfully we have to plan the experimental work according to the following flow chart.




WORKPIECE FIXTURE ARRANGEMENT
PROPER FIXING OF WORKPIECE
FLATNESS OF WORKPIECE
PERPENDICULARITY OF ELECTRODE
SPARK GAP SETTING
JET FLUSHING NOZZLE SETTING
FEED DATA IN CONTROL UNIT
MACHINING OF WORKPIECE
FINISHED PRODUCT

1. **EDM machine selection**

The electrical discharge machining (EDM) is one of the latest non-traditional machining processes, based on thermoelectric energy between the workpiece and tool. The performance of the process, to a large extent, depends on the tool material, workpiece material & manufacturing method of the tool. A suitable selection of tool can reduce the cost of machining. The performance of EDM is find out on the basis of Material Removal Rate (MRR), Overcut (OC), Tool Wear Rate (TWR) and Surface Roughness (SR). The important machining parameters of EDM which affecting on the performance parameters are discharge current, pulse on time, pulse off time, arc gap, flushing pressure, voltage and duty cycle. In this experimental procedure ELECTROLUX EDM Machine (Model No. : D7130) is used for machining of workpiece. Total 45 number of experiments by using 3 electrodes was conducted on SS-304 material in Electrical Discharge Machining.

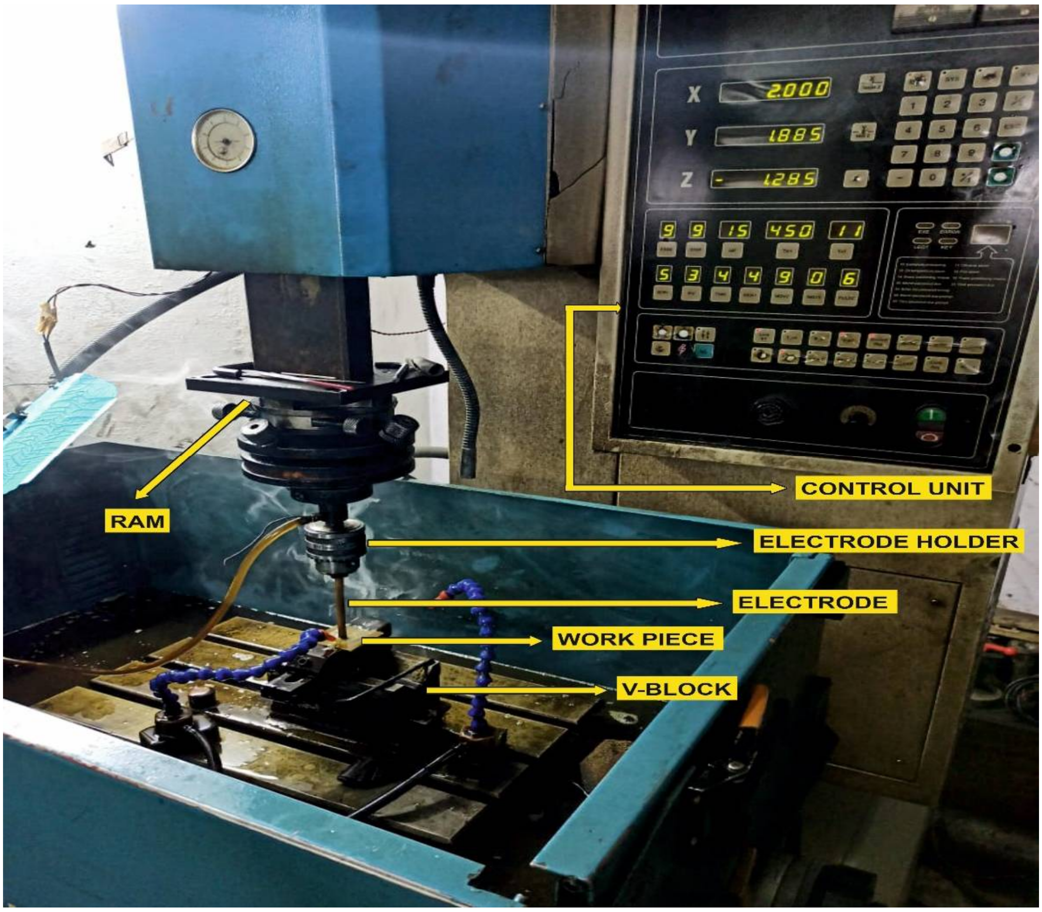


Fig. 3.2.1 EDM Machine

2. Selection of workpiece material

In this experiment AISI 304 stainless steel of size 50×50×5 mm3 plate is chosen for conducting the experiment. Grade 304 is the commonly used stainless steel; it is the utmost versatile applications and greatest use of stainless steel, offered in an extensive variety of good products, practices and qualities than any other. It has wonderful welding and forming characteristics. Grade 304 is freely brake or spool molded into a variability of work uses in the manufacturing, construction as well as automobile fields. The austenitic configuration provides these grades brilliant toughness, straight down to lower hotness.

It has excellent oxidization prevention in a numerous range of full of atmosphere environments as well as lots of corrosive medium. It has good corrosion resistance in intermittent service and brilliant weld ability property.

Fig. 3.2.A EDM Work piece- stainless steel 304

3. Selection of electrode

Material demonstrating good electrical conductivity can be used as EDM electrode. Materials with higher thermal conductivity are suitable as tool electrodes as well as materials with higher melting point and boiling point. Moreover, due to the high pressure and temperature present on the electrode during EDM machining, the electrode material must have acceptable mechanical strength and melting point to reduce tool wear and edge weakness. The study is carried out while machining SS-304 material in Electrical Discharge machining (EDM) using three electrode materials (**Copper chromium zirconium alloy, Beryllium copper and Copper Tungsten**). The effect of machining parameters such as Voltage, Current and Spark gap on the Electrode wear of machined work piece were inspected and optimized. when selecting an electrode material, one has to keep in mind the properties that influence the EDM process. Materials with high electrical conductivity and high thermal conductivity are suitable as tool electrodes, as well as materials with high melting and boiling points are adequate to be used as EDM electrodes.

Fig. 3.2B EDM Electrode

4. V-block and Tool holder arrangement

Tool holder and V-Block is arranged in such a manner that machining process should be in desired direction. Fig. 3.2C explains about the V-block and Tool holder arrangement

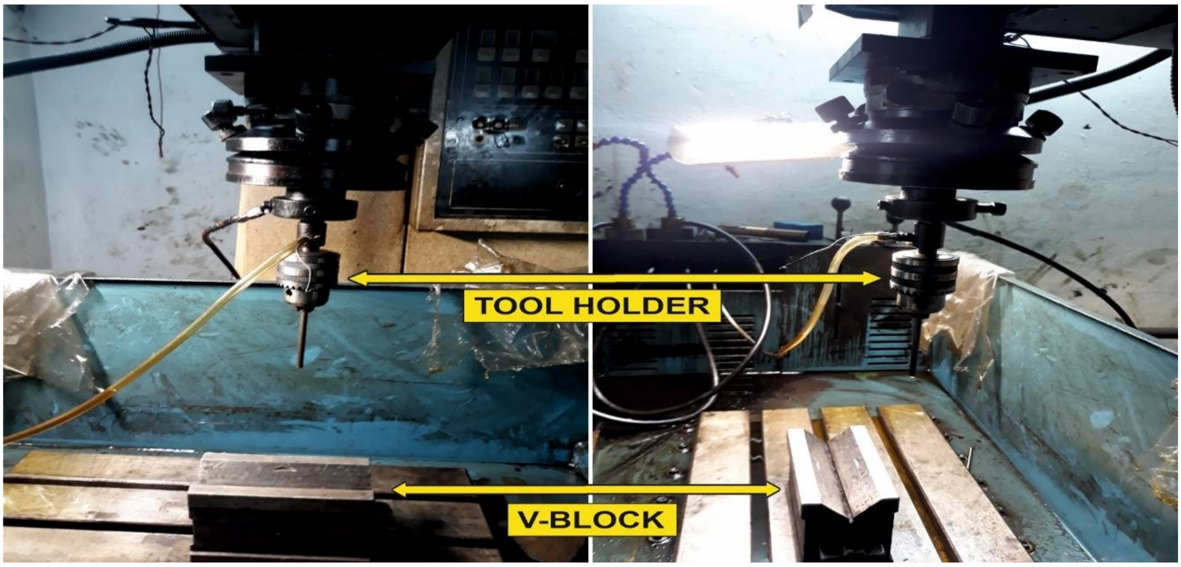


Fig. 3.2C V-Block and Tool Holder arrangement

5. Work piece fixture arrangement - In this experimental procedure we have to fix work piece in a proper manner for that reason we will arrange some proper fixture to hold the work piece during machining process.

Fig. 3.2D work piece fixture arrangement

6. Proper fixing of work piece - During the process of electrical discharge machining of work piece, lots of vibrational forces will be applied on the surface. So it is required to fix work piece properly.

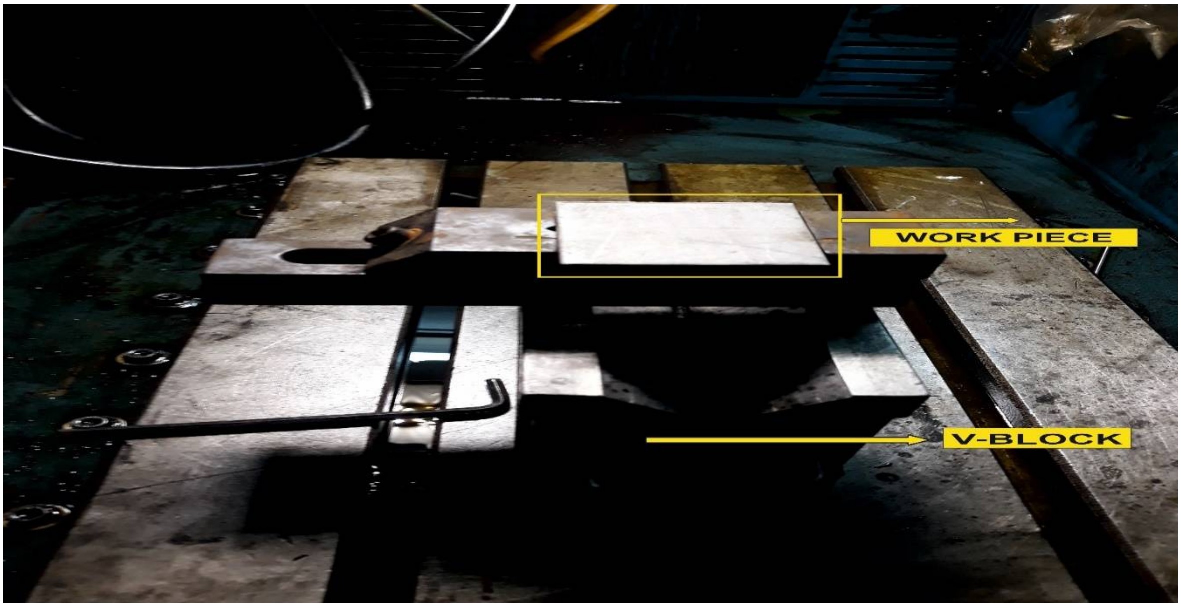


Fig. 3.2E proper fixing of work piece

7. Flatness of workpiece -Square work piece of SS-304 is put on V-block in a flat position so that the desired hole will be in a proper direction. This will also maintain the ovality of the hole. Fig. 3.2F shows the workpiece position on V-block.

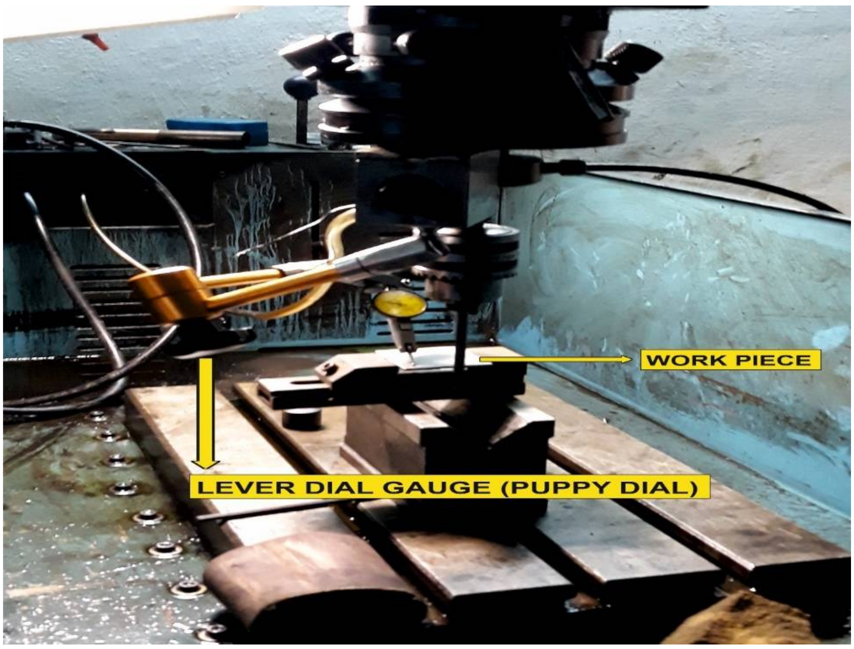


Fig. 3.2F Flatness of workpiece

8. Perpendicularity of electrode

Perpendicularity of electrode should be maintaining before performing the machining operation on EDM machine. Fig. 3.2G explains about the Perpendicularity of the electrode.

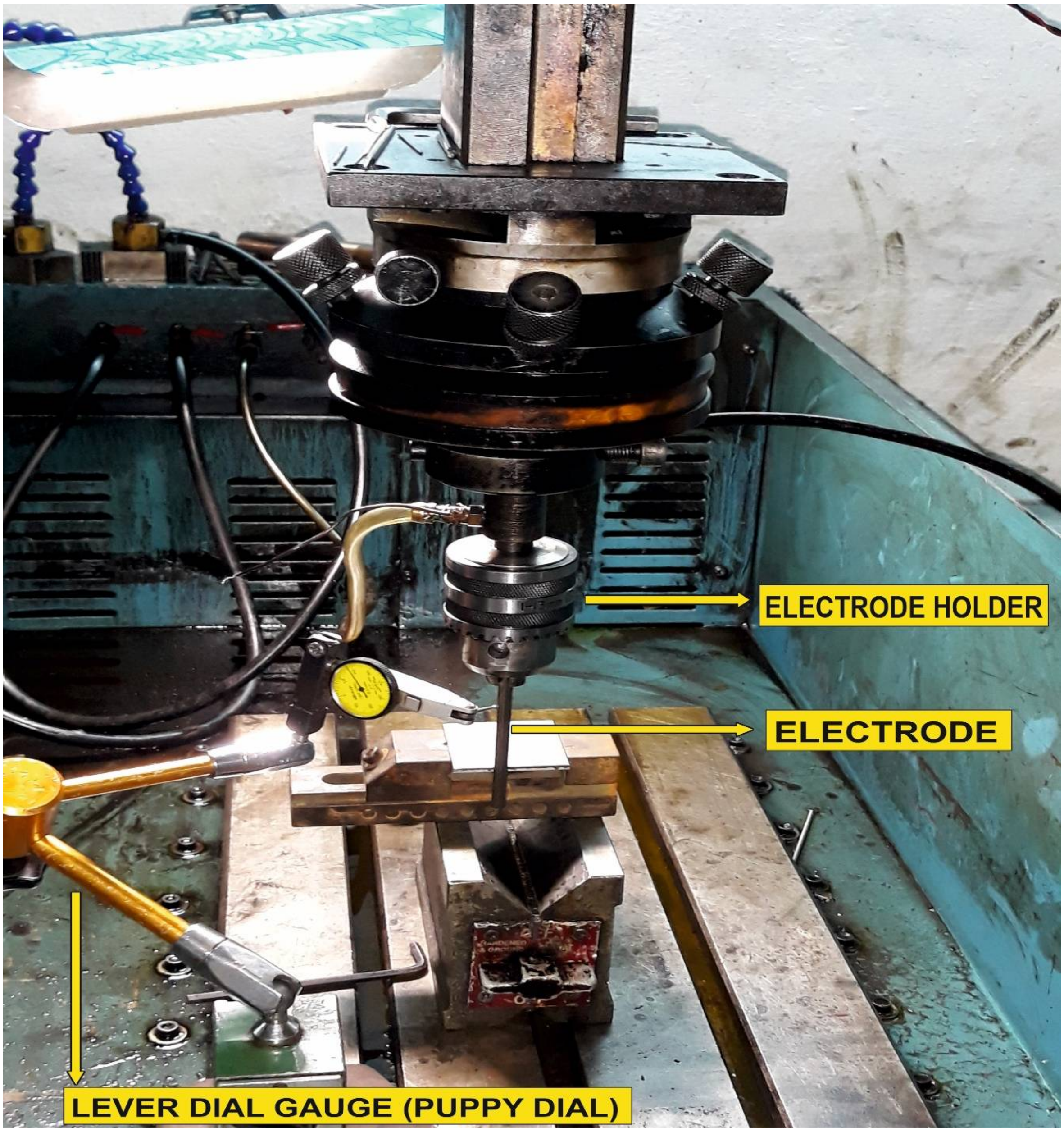


Fig. 3.2G perpendicularity of electrode

9. Gap Setting

Gap between Tool electrode and Workpiece must be maintain before machining operation. This Gap is generally 0.025 mm. Fig. 3.2H shows the Gap setting of Tool electrode and Workpiece.

Fig. 3.2H Gap Setting

10. Jet Flushing Nozzle Setting

Position of Jet flushing nozzle should be maintaining in such a way that eroded particles from workpiece removed properly. This helps to avoid carbon submission on Tool electrode and Workpiece. Fig. 3.2I shows Jet flushing nozle setting.

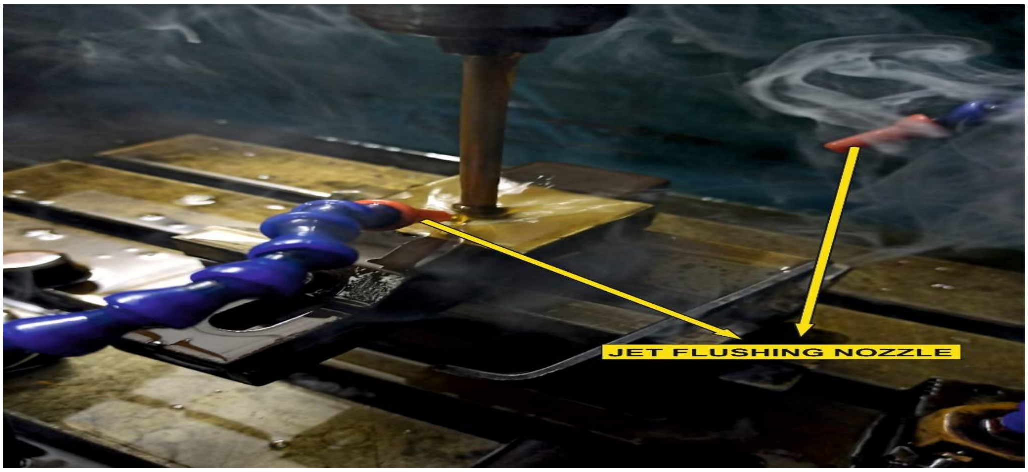


Fig. 3.2I Jet Flushing Nozzle Setting

11. Feed data in control unit

When experiment is about to perform we have to put the values in control unit of machine. First we will set the value of pulse current and depth of cut in control unit. Fig. 3.2J explains about the control unit of machine.

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Fig. 3.2J Control Unit

12. Machining of workpiece

Now the experiment will performed on machine. Fig. 3.2K shows the electrical discharge machining of workpiece.

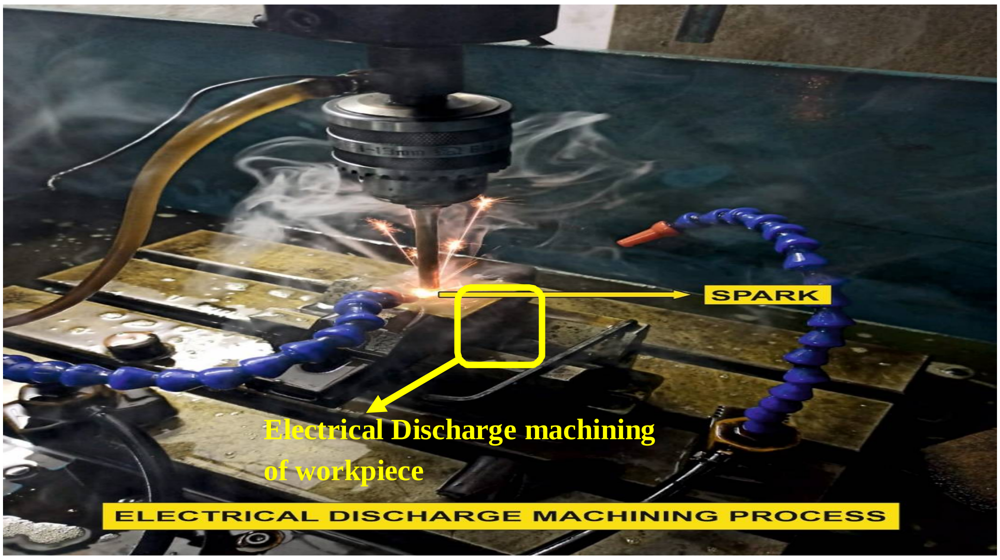

Fig. 3.2K Machining of Workpiece

13. Finished work piece

After machining process in this experimental work we will get the 2 mm depth hole into the work piece surface**.**

Fig. 3.2L Finished product

3.3 Input Parameters

3.3.1 Pulse Current

The discharge current (Id) is a measure of the amount of electrical charges flowing between the tool and workpiece electrode. As the flow of electrical charges is the heating mechanism in electro thermal erosion. In this experimental procedure three level of pulse current 5A, 8A and 11A are used.

3.3.2 Tool Electrode Material

In this research work, electrode materials like copper, brass and copper tungsten were taken for machining of stainless steel - 202. The electrical discharge machining has been conducted with these electrodes. The analysis has been made on electrode wear and MRR.

3.3.3 Polarity

In this experimental procedure electrode polarity is positive. Polarity of the electrode can be either positive or negative.

i. Straight polarity: Electrode (-) &workpiece (+)

ii. Reverse polarity: Electrode (+) &workpiece (-)

3.3.4 Gap Voltage

In this experimental study 50V, 60V and 70V voltage are used. The preset gap-voltage determines the width of the spark gap between the leading edge of the electrode and the workpiece.

3.3.5 On-time or pulse time

It is the duration of time (µs) for which the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time.

3.3.6 Off-time or Pause time

It is the duration of time between the sparks. This time allows the molten material to solidify and to be wash out of the arc gap.

3.3.7 Arc Gap

It is the distance between the electrode and the workpiece during the process of EDM. It may be called as the spark gap.

3.3.8 Duty Cycle

It is the percentage of on-time relative to total cycle time. This parameter is calculated by dividing the on-time by the total cycle time (on-time plus off-time). The result is multiplied by 100 for the percentage of efficiency.

3.3.9 Intensity

It points out the different levels of power that can be supplied by the generator of the EDM machine.

3.3.10 Injection Pressure

Injection pressure is for selection of flushing input pressure of the dielectric. Dielectric fluid rushes into the work piece to cool the area and remove eroded material. Input pressure of de-ionized water has a direct relation with the work piece thickness.

3.4 Experiments

3.4.1 Experiment 1

In our first experiment Copper chromium zirconium is used as a Tool Electrode. In this experiment pulse current - 5 ampere, T_{on} time - 450 µsec, T_{off} time – 11 µsec. Electrode pause time – 9 sec are used as an input parameters. In this experiment Gap Voltage is 75 Volt. Polarity of tool electrode is Positive. Commercial EDM grade oil is used as a Dielectric fluid. Fig. 3.4A & 3.4B give the information of the experiment no.1.

Fig. 3.4A Control unit for Copper chromium zirconium Electrode at 5A

Fig. 3.4B Experiment with Copper chromium zirconium Electrode at 5A

3.4.2 Experiment 2

In our second experiment again Copper chromium zirconium is used as a Tool Electrode. In this experiment pulse current - 10 ampere, T_{on} time - 450 µsec, T_{off} time – 11 µsec. Electrode pause time – 9 sec are used as an input parameters. In this experiment Gap Voltage is 85 Volt. Polarity of tool electrode is Positive. Commercial EDM grade oil is used as a Dielectric fluid.Fig. 3.4C & 3.4D explain the experiment no.2

Fig. 3.4C Control unit for Copper chromium zirconium Electrode at 10A

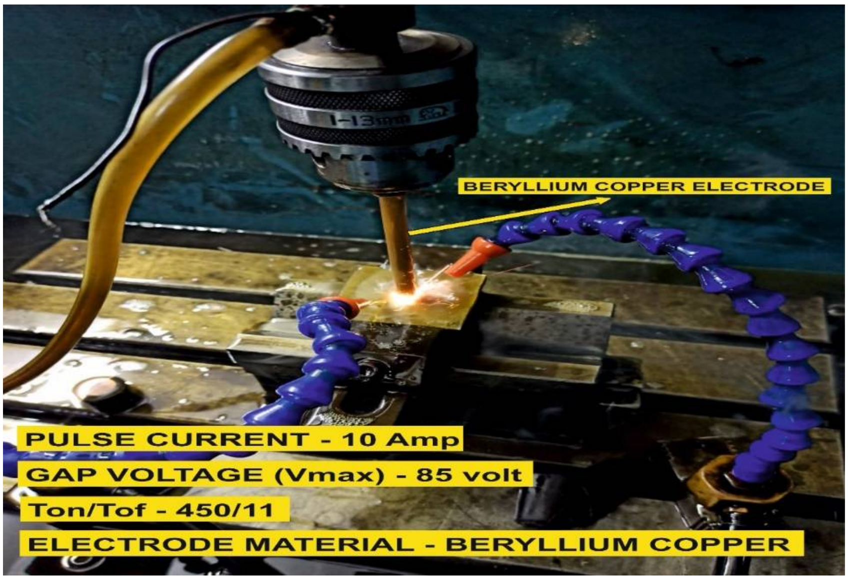

Fig. 3.4D Experiment with Copper chromium zirconium Electrode at 10A

3.4.3 Experiment 3

In our third experiment again Copper chromium zirconium is used as a Tool Electrode. In this experiment pulse current - 15 ampere, T_{on} time - 450 µsec, T_{off} time – 11 µsec. Electrode pause time – 9 sec are used as an input parameters. In this experiment Gap Voltage is 95 Volt. Polarity of tool electrode is Positive. Commercial EDM grade oil is used as a Dielectric fluid. Fig. 3.4E & 3.4F describe the experiment no.3

Fig. 3.4E Control unit for Copper chromium zirconium Electrode at 15A

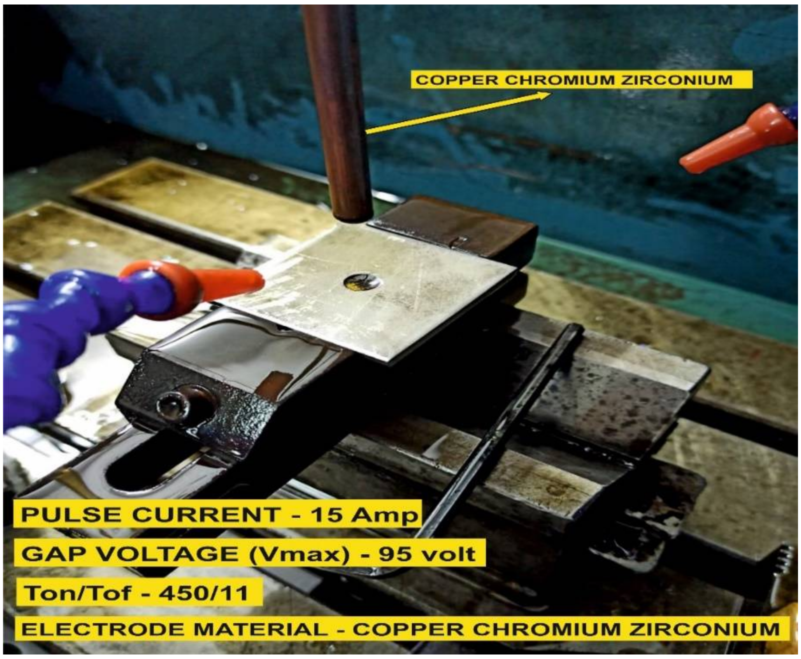

Fig. 3.4F Experiment with Copper chromium zirconium Electrode at 15A

3.4.4 Experiment 4

In our fourth experiment Beryllium copper is used as a Tool Electrode. In this experiment pulse current - 5 ampere, T_{on} time – 450 µsec, T_{off} time – 11 µsec. Electrode pause time – 9 sec are used as an input parameters. In this experiment Gap Voltage is 75 Volt. Polarity of tool electrode is Positive. Commercial EDM grade oil is used as a Dielectric fluid .Fig. 3.4G & 3.4H represent the experiment no.4

Fig. 3.4G Control unit for Beryllium Copper Electrode at 5A

Fig. 3.4H Experiment with Beryllium Copper Electrode at 5A

3.4.5 Experiment 5

In our fifth experiment again Copper chromium zirconium is used as a Tool Electrode. In this experiment pulse current - 10 ampere, T_{on} time - 450 µsec, T_{off} time – 11 µsec. Electrode pause time – 9 sec are used as the input parameters. In this experiment Gap Voltage is 85 Volt. Polarity of tool electrode is Positive. Commercial EDM grade oil is used as a Dielectric fluid. Fig. 3.4I & 3.4J give the information of experiment no.5

Fig. 3.4I Control unit for Beryllium Copper Electrode at 10A

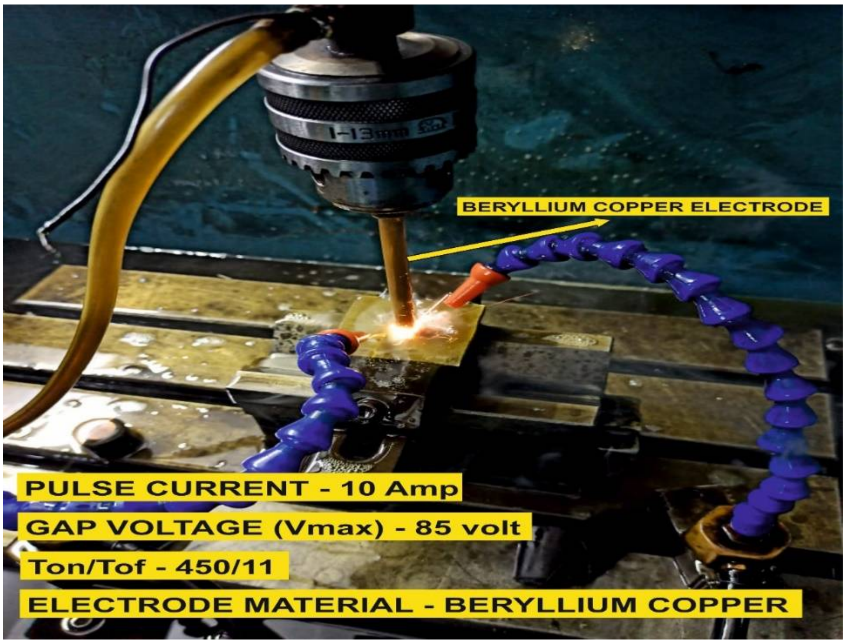

Fig. 3.4J Experiment with Beryllium Copper Electrode at 10A

3.4.6 Experiment 6

In our sixth experiment again Copper chromium zirconium is used as a Tool Electrode. In this experiment pulse current - 15 ampere, T_{on} time - 450 µsec, T_{off} time – 11 µsec. Electrode pause time – 9 sec are used as an input parameters. In this experiment Gap Voltage is 95 Volt. Polarity of tool electrode is Positive. Commercial EDM grade oil is used as a Dielectric fluid. Fig. 3.4K & 3.4L describe the experiment no.6

Fig. 3.4K Control unit for Beryllium Copper Electrode at 15A

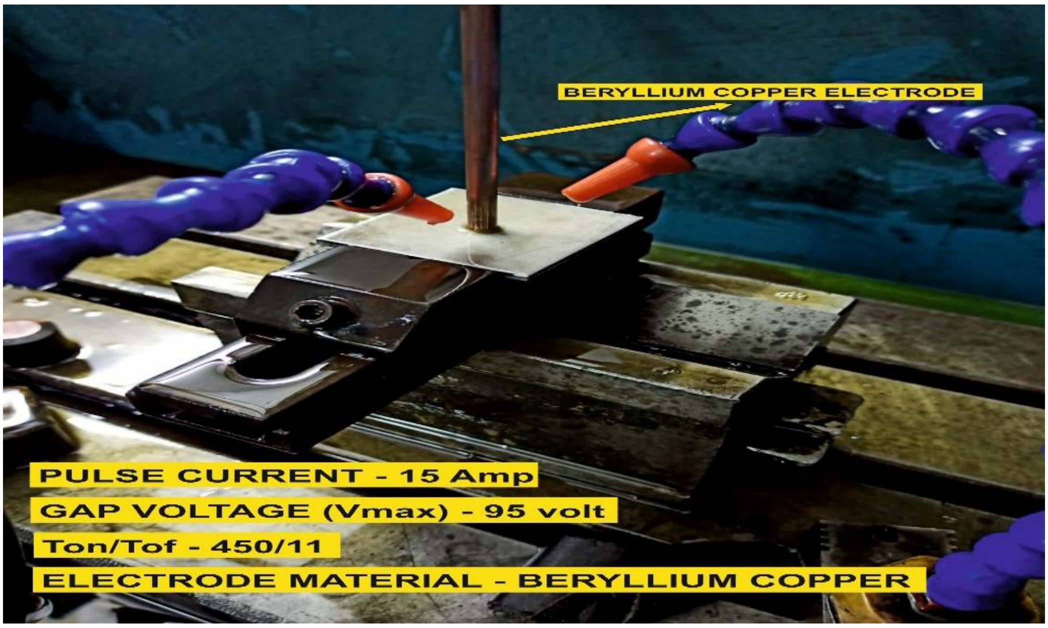

Fig. 3.4L Experiment with Beryllium Copper Electrode at 15A

3.4.7 Experiment 7

In our seven experiment Copper Tungsten is used as a Tool Electrode. In this experiment pulse current - 5 ampere, T_{on} time - 450 µsec, T_{off} time – 11 µsec. Electrode pause time – 9 sec are used as an input parameters. In this experiment Gap Voltage is 75 Volt. Polarity of tool electrode is Positive. Commercial EDM grade oil is used as a Dielectric fluid.Fig. 3.4M & 3.4N explain the experiment no.7

Fig. 3.4M Control unit for Copper Tungsten Electrode at 5A

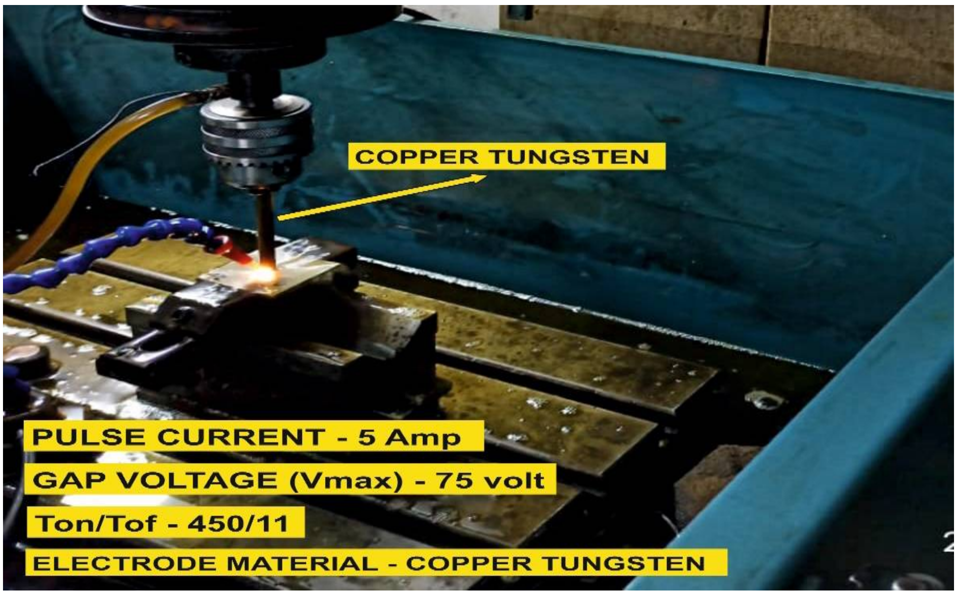

Fig. 3.4L Experiment with Copper Tungsten Electrode at 5A

3.4.8 Experiment 8

In our eight experiment again Copper Tungsten s is used as a Tool Electrode. In this experiment pulse current - 10 ampere, T_{on} time - 450 µsec, T_{off} time – 11 µsec. Electrode pause time – 9 sec are used as an input parameters. In this experiment Gap Voltage is 85 Volt. Polarity of tool electrode is Positive. Commercial EDM grade oil is used as a Dielectric fluid.Fig. 3.4O & 3.4P describe the experiment no.8

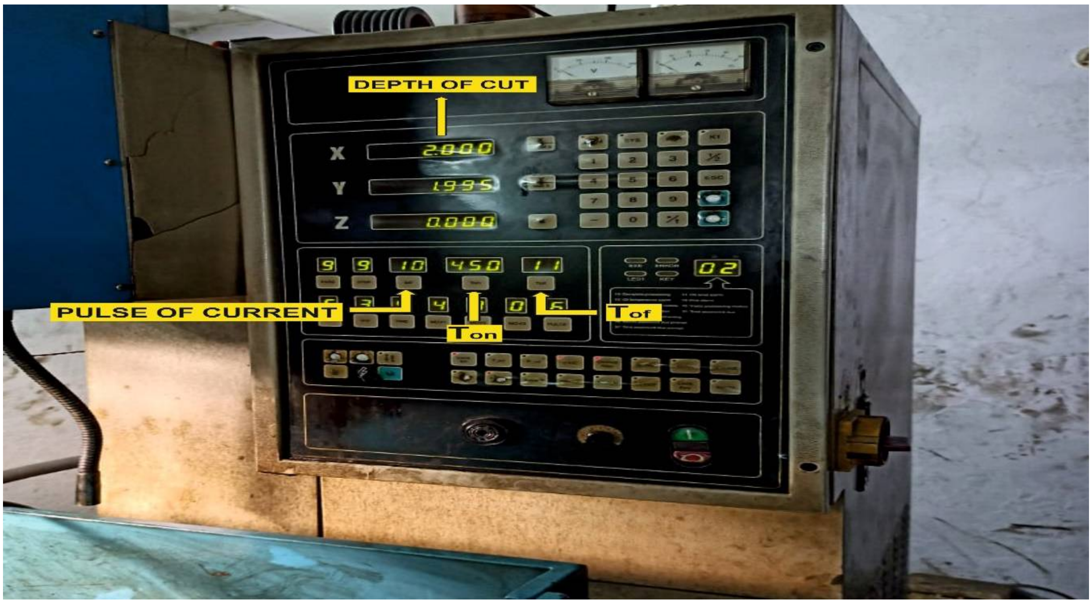

Fig. 3.4O Control unit for Copper Tungsten Electrode at 10A

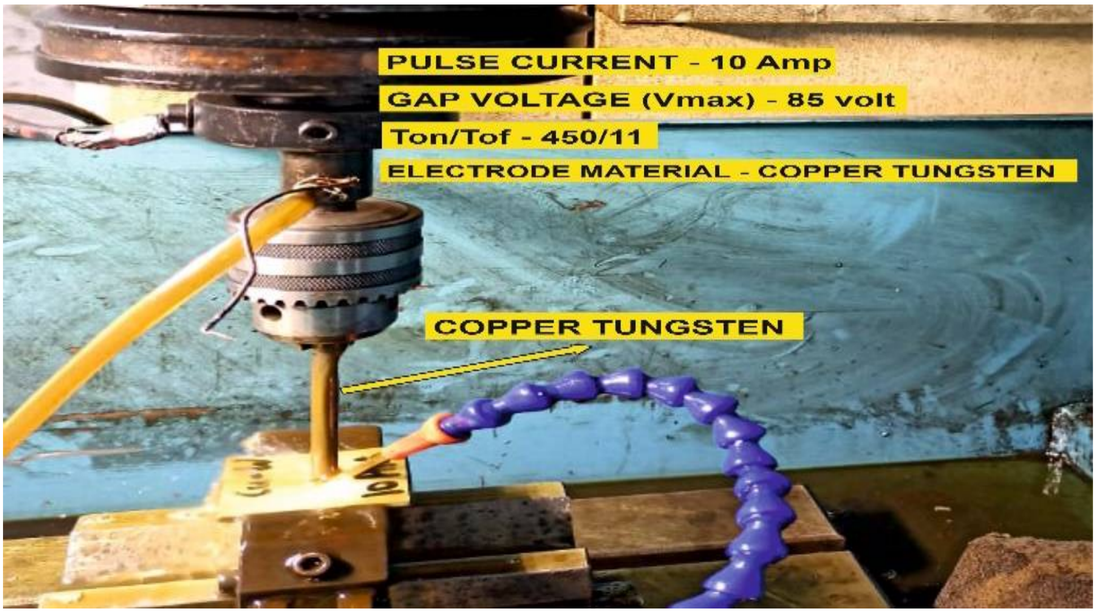

Fig. 3.4P Experiment with Copper Tungsten Electrode at 10A

3.4.9 Experiment 9

In our nine experiment again Copper Tungsten is used as a Tool Electrode. In this experiment pulse current - 15 ampere, T_{on} time - 450 µsec, T_{off} time – 11 µsec. Electrode pause time – 9 sec are used as an input parameters. In this experiment Gap Voltage is 95 Volt. Polarity of tool electrode is Positive. Commercial EDM grade oil is used as a Dielectric fluid.Fig. 3.4Q & 3.4R describe the experiment no.9

Fig. 3.4Q Control unit for Copper Tungsten Electrode at 15A

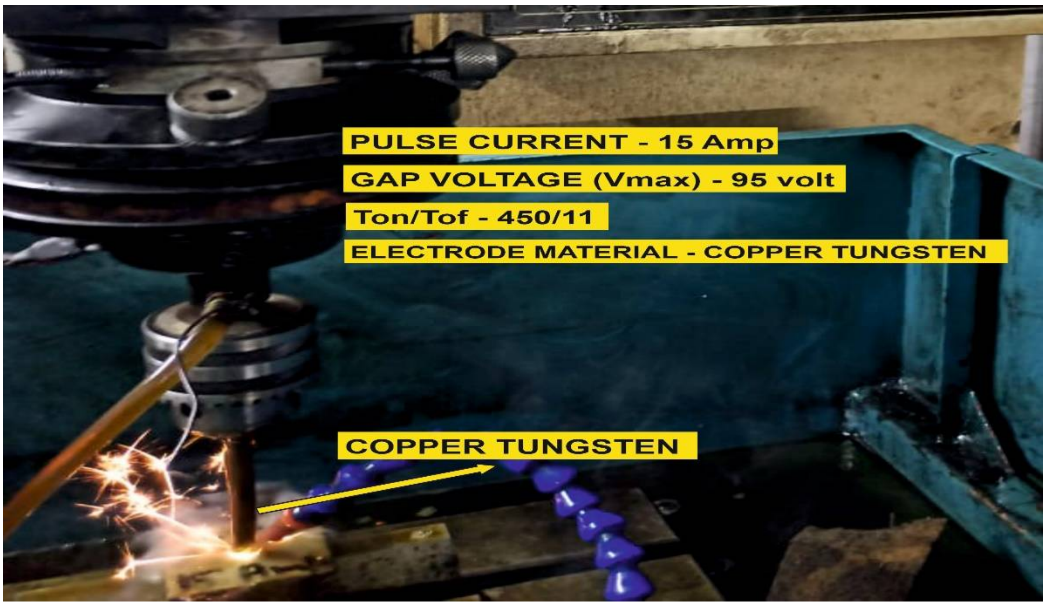

Fig. 3.4R Experiment with Copper Tungsten Electrode at 15A

CHAPTER – 4

RESULTS AND DISCUSSION

4.1 Introduction

This project work investigates the performance of copper chromium zirconium, copper tungsten and beryllium copper electrode on machining characteristics of stainless steel SS-304 in the electrical discharge machine (EDM) die sinking. The relationship between the machining parameters such as peak current, voltage, pulse-on time, and pulse-off time on machining characteristics was studied. The experiments were carried out for 2 mm depth of cut. In this experimental procedure three pulse current settings of 5A, 10A and 15A is used with the application of copper chromium zirconium, copper tungsten and beryllium copper electrode.

4.6 Electrode Wear Rate

Electrode Wear Rate (EWR) is defined as the ratio of difference of Mass for tool electrode before and after machining process to the machining time.

$$\text{EWR} = \frac{W_b - W_a}{T}$$

S.NO.	ELECTRODE	PULSE CURRENT (Ampere)	MASS of Electrode BEFORE	MASS of Electrode AFTER	TIME
1	COPPER CHROMIUM ZIRCONIUM	5	49.752	49.736	42 min 15 sec
2	COPPER CHROMIUM ZIRCONIUM	5	49.736	49.712	42 min 19 sec
3	COPPER CHROMIUM ZIRCONIUM	5	49.712	49.681	42 min 25 sec
4	COPPER CHROMIUM ZIRCONIUM	5	49.681	49.653	42 min 22 sec
5	COPPER CHROMIUM ZIRCONIUM	5	49.653	49.621	42 min 17 sec
6	COPPER CHROMIUM ZIRCONIUM	10	49.621	49.607	9 min 30 sec
7	COPPER CHROMIUM ZIRCONIUM	10	49.607	49.584	9 min 15 sec

8	COPPER CHROMIUM ZIRCONIUM	10	49.584	49.561	9 min 45 sec
9	COPPER CHROMIUM ZIRCONIUM	10	49.561	49.538	9 min 40 sec
10	COPPER CHROMIUM ZIRCONIUM	10	49.538	49.523	9 min 15 sec
11	COPPER CHROMIUM ZIRCONIUM	15	49.523	49.514	5 min 02 sec
12	COPPER CHROMIUM ZIRCONIUM	15	49.514	49.496	5 min 08 sec
13	COPPER CHROMIUM ZIRCONIUM	15	49.496	49.491	5 min 12 sec
14	COPPER CHROMIUM ZIRCONIUM	15	49.491	49.485	5 min 07 sec
15	COPPER CHROMIUM ZIRCONIUM	15	49.485	49.482	5 min 11 sec
16	BERYLLIUM COPPER	5	29.662	29.651	22 min 01 sec
17	BERYLLIUM COPPER	5	29.651	29.645	22 min 06 sec
18	BERYLLIUM COPPER	5	29.645	29.639	22 min 04 sec
19	BERYLLIUM COPPER	5	29.639	29.636	22 min 08 sec
20	BERYLLIUM COPPER	5	29.636	29.634	22 min 12 sec
21	BERYLLIUM COPPER	10	29.634	29.628	05 min 14 sec
22	BERYLLIUM COPPER	10	29.628	29.624	05 min 18 sec
23	BERYLLIUM COPPER	10	29.624	29.618	05 min 21 sec
24	BERYLLIUM COPPER	10	29.618	29.611	05 min 08 sec
25	BERYLLIUM COPPER	10	29.611	29.593	05 min 12 sec
26	BERYLLIUM COPPER	15	29.593	29.581	03 min 36 sec
27	BERYLLIUM COPPER	15	29.581	29.572	03 min 32 sec
28	BERYLLIUM COPPER	15	29.572	29.565	03 min 38 sec
29	BERYLLIUM COPPER	15	29.565	29.561	03 min 34 sec
30	BERYLLIUM COPPER	15	29.561	29.556	03 min 37 sec
31	COPPER TUNGSTEN	5	39.968	39.963	110 min 30 sec
32	COPPER TUNGSTEN	5	39.963	39.958	110 min 32 sec

33	COPPER TUNGSTEN	5	39.958	39.956	110 min 34 sec
34	COPPER TUNGSTEN	5	39.956	39.951	110 min 38 sec
35	COPPER TUNGSTEN	5	39.951	39.946	110 min 26 sec
36	COPPER TUNGSTEN	10	39.946	39.943	32 min 50 sec
37	COPPER TUNGSTEN	10	39.943	39.941	32 min 52 sec
38	COPPER TUNGSTEN	10	39.941	39.938	32 min 55 sec
39	COPPER TUNGSTEN	10	39.938	39.936	32 min 48 sec
40	COPPER TUNGSTEN	10	39.936	39.935	32 min 51 sec
41	COPPER TUNGSTEN	15	39.935	39.934	14 min 14 sec
42	COPPER TUNGSTEN	15	39.934	39.931	14 min 18 sec
43	COPPER TUNGSTEN	15	39.931	39.929	14 min 12 sec
44	COPPER TUNGSTEN	15	39.929	39.928	14 min 16 sec
45	COPPER TUNGSTEN	15	39.928	39.925	14 min 15 sec

4.6.1 EWR with COPPER CHROMIUM ZIRCONIUM Electrode at 5A

EWR of work piece SS-304 with respect to 5A Pulse current is shown in the Table. 4.6A and variation is represented in the Fig. 4.6A which shows the change of electrode wear rate using Copper chromium zirconium electrode at 5 ampere.

Table. 4.6A Data collection of EWR at 5A

Exp No.	Mass of electrode before	Mass of electrode after	Time (Minutes)	Difference of Mass	Electrode Wear Rate
1	49.752	49.736	42.25	0.016	0.0004
2	49.736	49.712	42.32	0.024	0.0006
3	49.712	49.681	42.42	0.031	0.0007
4	49.681	49.653	42.36	0.028	0.0007
5	49.653	49.621	42.28	0.032	0.0008

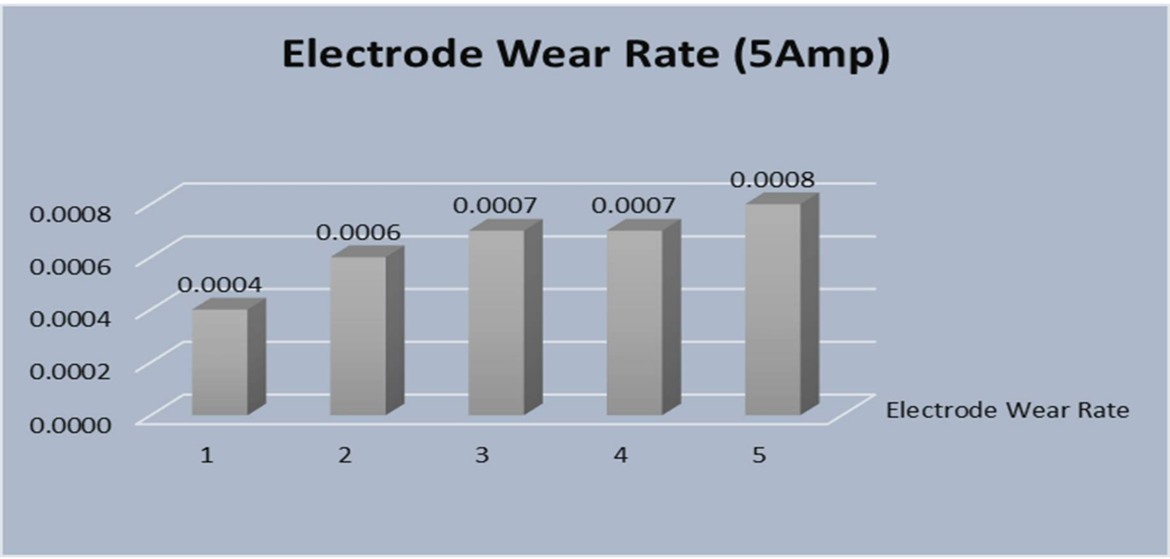

Fig. 4.6A Variation of EWR using Copper chromium zirconium electrode at 5A

4.6.2 EWR with COPPER CHROMIUM ZIRCONIUM Electrode at 10A

EWR of workpiece SS-304 with respect to 10A Pulse current is shown in the Table. 4.6B and variation is represented in the Fig. 4.6B which shows the change of electrode wear rate using COPPER CHROMIUM ZIRCONIUM electrode at 10 ampere.

Table. 4.6B Data collection of EWR at 10A

Exp No.	Mass of electrode before	Mass of electrode after	Time (Minutes)	Difference of Mass	Electrode Wear Rate
1	49.621	49.607	9.5	0.014	0.0015
2	49.607	49.584	9.25	0.023	0.0025
3	49.584	49.561	9.75	0.023	0.0024
4	49.561	49.538	9.67	0.023	0.0024
5	49.538	49.523	9.25	0.015	0.0016

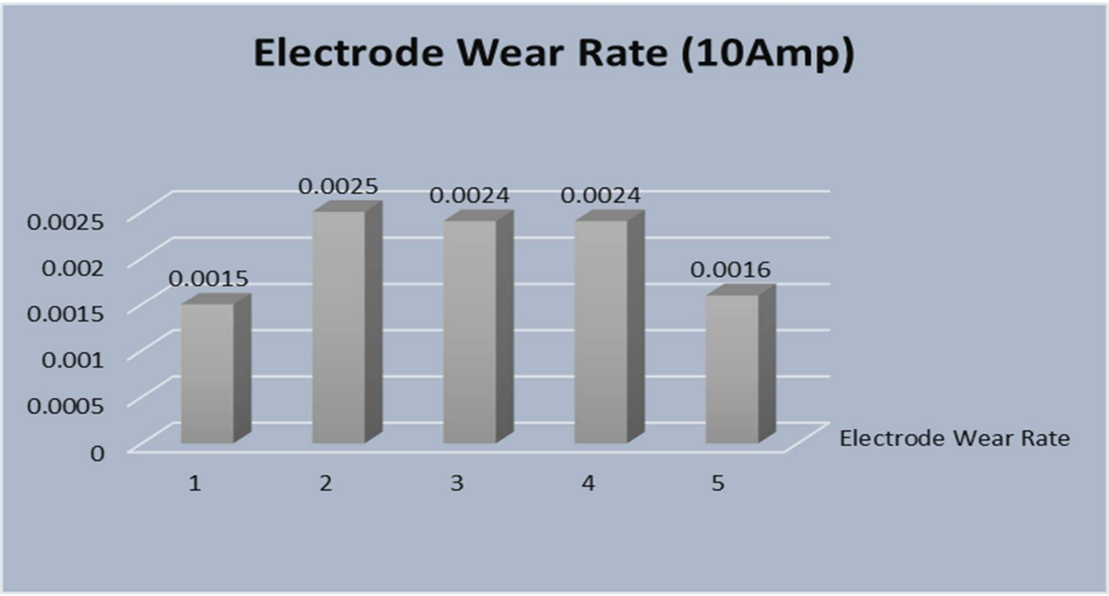

Fig. 4.6B Variation of EWR using Copper chromium zirconium electrode at 10A

4.6.3 EWR with COPPER CHROMIUM ZIRCONIUM Electrode at 15A

EWR of workpiece SS-304 with respect to 15A Pulse current is shown in the Table. 4.6C and variation is represented in the Fig. 4.6C which shows the change of electrode wear rate using COPPER CHROMIUM ZIRCONIUM electrode at 15 ampere.

Table. 4.6C Data collection of EWR at 11A

Exp No.	Mass of electrode before	Mass of electrode after	Time (Minutes)	Difference of Mass	Electrode Wear Rate
1	49.523	49.514	5.03	0.009	0.0018
2	49.514	49.496	5.13	0.018	0.0035
3	49.496	49.491	5.2	0.005	0.0010
4	49.491	49.485	5.17	0.006	0.0012
5	49.485	49.482	5.18	0.003	0.0006

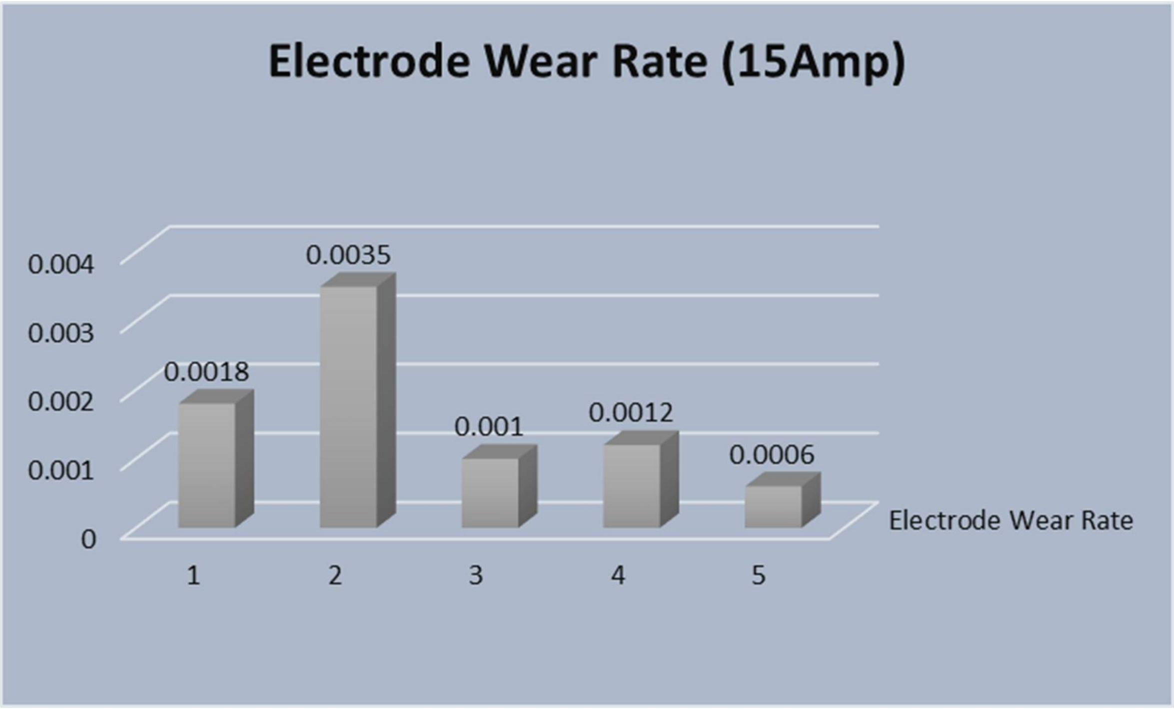

Fig. 4.6C Variation of EWR using Copper chromium zirconium electrode at 15A

4.7 ELECTRODE WEAR RATE USING BERYLLIUM COPPER ELECTRODE

4.7.1 EWR with Beryllium Copper Electrode at 5A

EWR of workpiece SS-304 with respect to 5A Pulse current is shown in the Table. 4.7A and variation is represented in the Fig. 4.7A which shows the change of electrode wear rate using Beryllium copper electrode at 5 ampere.

Table. 4.7A Data collection of EWR at 5A

Exp No.	Mass of electrode before	Mass of electrode after	Time (Minutes)	Difference of Mass	Electrode Wear Rate
1	29.662	29.651	22.02	0.0110	0.000499546
2	29.651	29.645	22.1	0.0060	0.000271493
3	29.645	29.639	22.07	0.0060	0.000271862
4	29.639	29.636	22.13	0.0030	0.000135563
5	29.636	29.634	22.2	0.0020	9.00901E-05

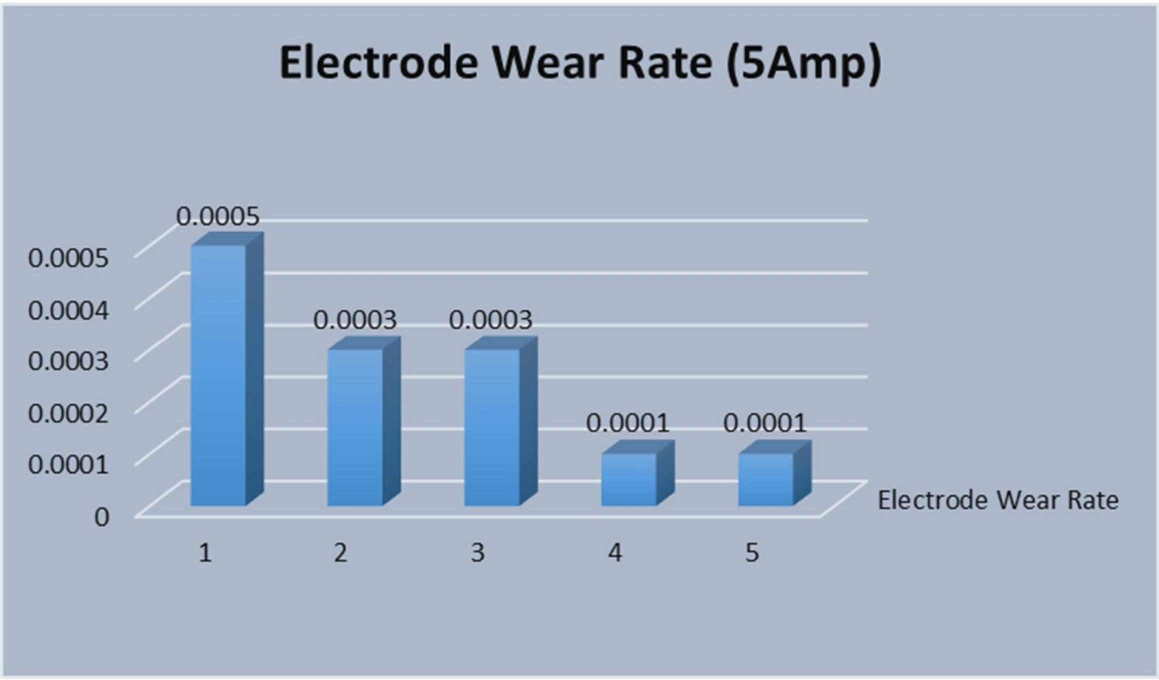

Fig. 4.7A Variation of EWR using Beryllium Copper electrode at 5A

4.7.2 EWR with Beryllium Copper Electrode at 10A

EWR of workpiece SS-304 with respect to 10A Pulse current is shown in the Table. 4.7B and variation is represented in the Fig. 4.7B which shows the change of electrode wear rate using Beryllium Copper electrode at 10 ampere.

Table. 4.7B Data collection of EWR at 10A

Exp No.	Mass of electrode before	Mass of electrode after	Time (Minutes)	Difference of Mass	Electrode Wear Rate
1	29.634	29.628	5.23	0.0060	0.001147228
2	29.628	29.624	5.3	0.0040	0.000754717
3	29.624	29.618	5.35	0.0060	0.001121495
4	29.618	29.611	5.13	0.0070	0.001364522
5	29.611	29.593	5.2	0.0180	0.003461538

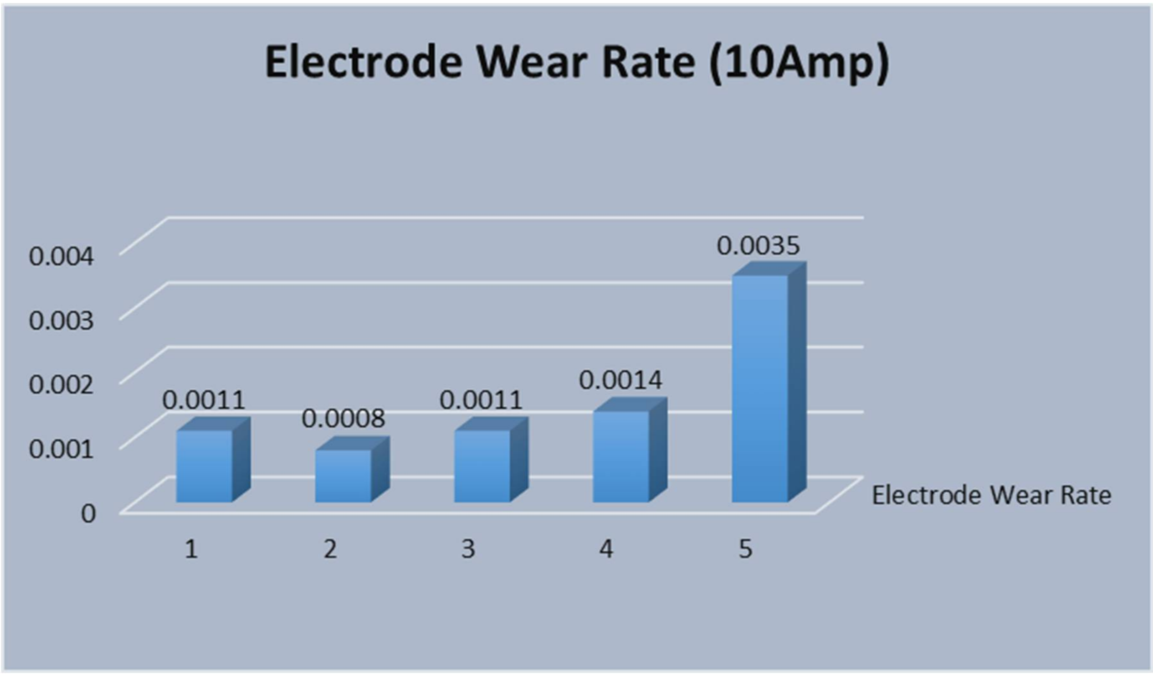

Fig. 4.7A Variation of EWR using Beryllium Copper electrode at 10A

4.7.3 EWR with Beryllium Copper Electrode at 15A

EWR of workpiece SS-304 with respect to 15A Pulse current is shown in the Table. 4.7C and variation is represented in the Fig. 4.7C which shows the change of electrode wear rate using Beryllium Copper electrode at 15 ampere.

Table. 4.7C Data collection of EWR at 15A

Exp No.	Mass of electrode before	Mass of electrode after	Time (Minutes)	Difference of Mass	Electrode Wear Rate
1	29.593	29.581	3.6	0.0120	0.003333333
2	29.581	29.572	3.53	0.0090	0.002549575
3	29.572	29.565	3.63	0.0070	0.001928375
4	29.565	29.561	3.56	0.0040	0.001123596
5	29.561	29.556	3.61	0.0050	0.001385042

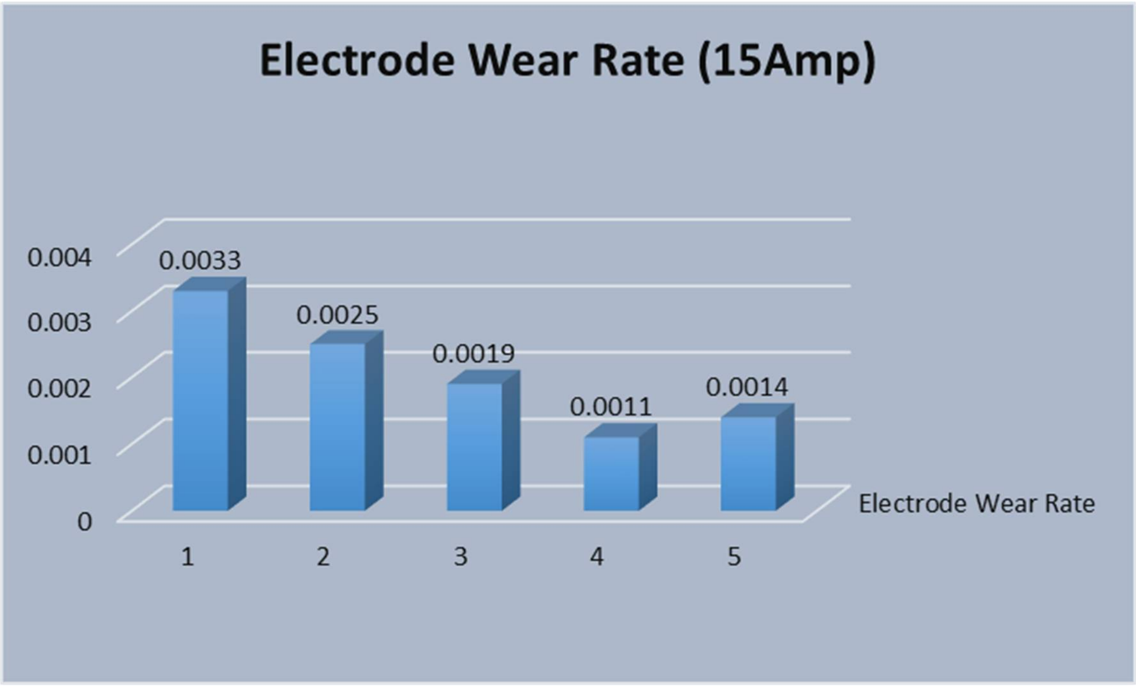

Fig. 4.7C Variation of EWR using Beryllium Copper electrode at 15A

4.8 ELECTRODE WEAR RATE USING Cu-W ELECTRODE

4.8.1 EWR with Copper Tungsten Electrode at 5A

EWR of workpiece SS-304 with respect to 5A Pulse current is shown in the Table. 4.8A and variation is represented in the Fig. 4.8A which shows the change of electrode wear rate using Copper Tungsten electrode at 5 ampere.

Table. 4.8A Data collection of EWR at 5A

Exp No.	Mass of electrode before	Mass of electrode after	Time (Minutes)	Difference of Mass	Electrode Wear Rate
1	39.968	39.963	110.5	0.005	0.000045
2	39.963	39.958	110.53	0.005	0.000045
3	39.958	39.956	110.56	0.002	0.000018
4	39.956	39.951	110.63	0.005	0.000045
5	39.951	39.946	110.43	0.005	0.000045

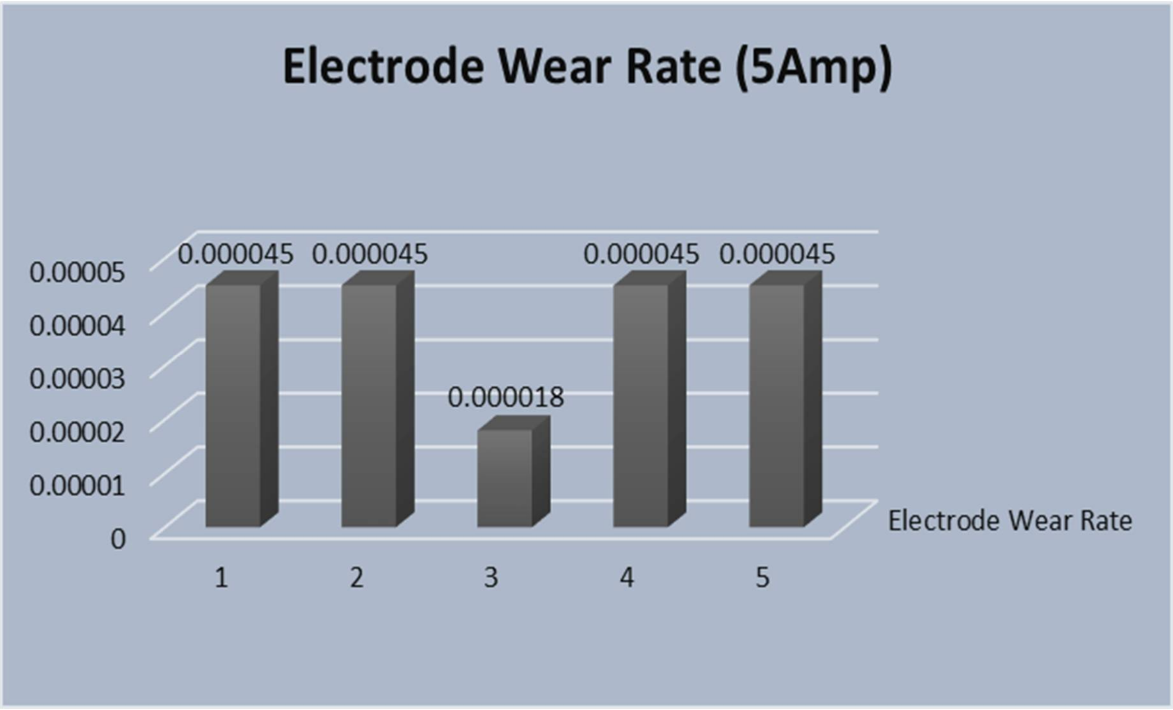

Fig. 4.8A Variation of EWR using Copper Tungsten electrode at 5A

4.8.2 EWR with Copper Tungsten Electrode at 10A

EWR of workpiece SS-304 with respect to 10A Pulse current is shown in the Table. 4.8B and variation is represented in the Fig. 4.8B which shows the change of electrode wear rate using Copper Tungsten electrode at 10 ampere.

Table. 4.8B Data collection of EWR at 10 A

Exp No.	Mass of electrode before	Mass of electrode after	Time (Minutes)	Difference of Mass	Electrode Wear Rate
1	39.946	39.943	32.83	0.003	0.000091
2	39.943	39.941	32.86	0.002	0.000061
3	39.941	39.938	32.91	0.003	0.000091
4	39.938	39.936	32.8	0.002	0.000061
5	39.936	39.935	32.85	0.001	0.000030

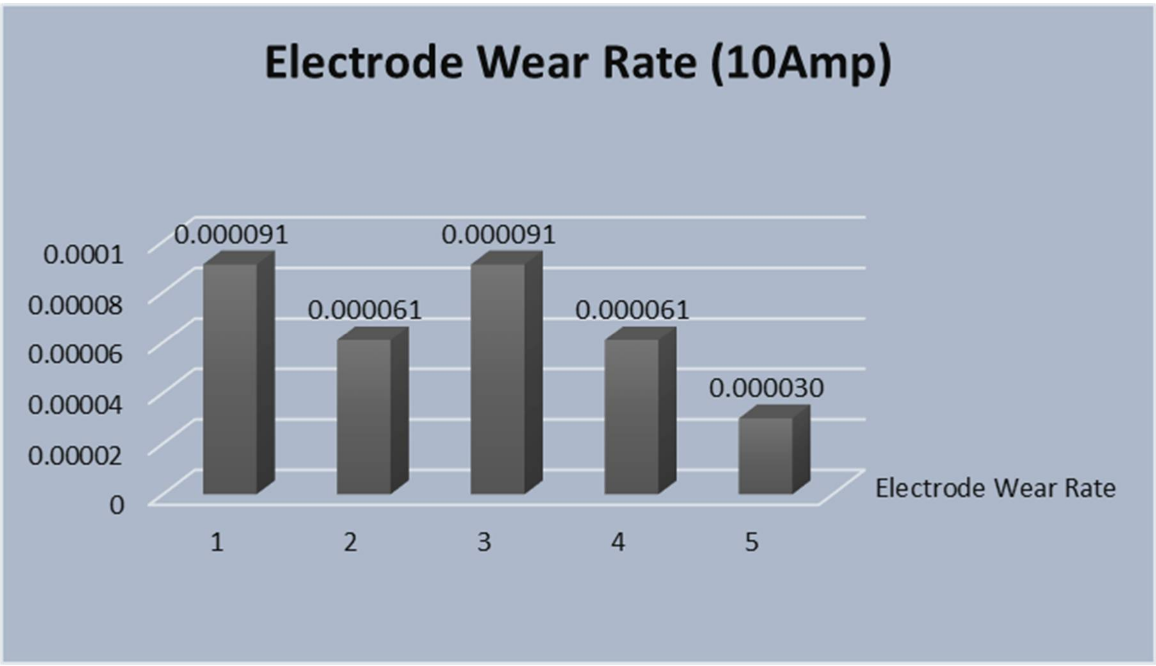

Fig. 4.8B Variation of EWR using Copper Tungsten electrode at 10A

4.8.3 EWR with Copper Tungsten Electrode at 15A

EWR of workpiece SS-304 with respect to 15A Pulse current is shown in the Table. 4.8C and variation is represented in the Fig. 4.8C which shows the change of electrode wear rate using Copper Tungsten electrode at 15 ampere.

Table. 4.8C Data collection of EWR at 15A

Exp No.	Mass of electrode before	Mass of electrode after	Time (Minutes)	Difference of Mass	Electrode Wear Rate
1	39.935	39.934	14.23	0.001	0.000070
2	39.934	39.931	14.3	0.003	0.000210
3	39.931	39.929	14.2	0.002	0.000141
4	39.929	39.928	14.26	0.001	0.000070
5	39.928	39.925	14.25	0.003	0.000211

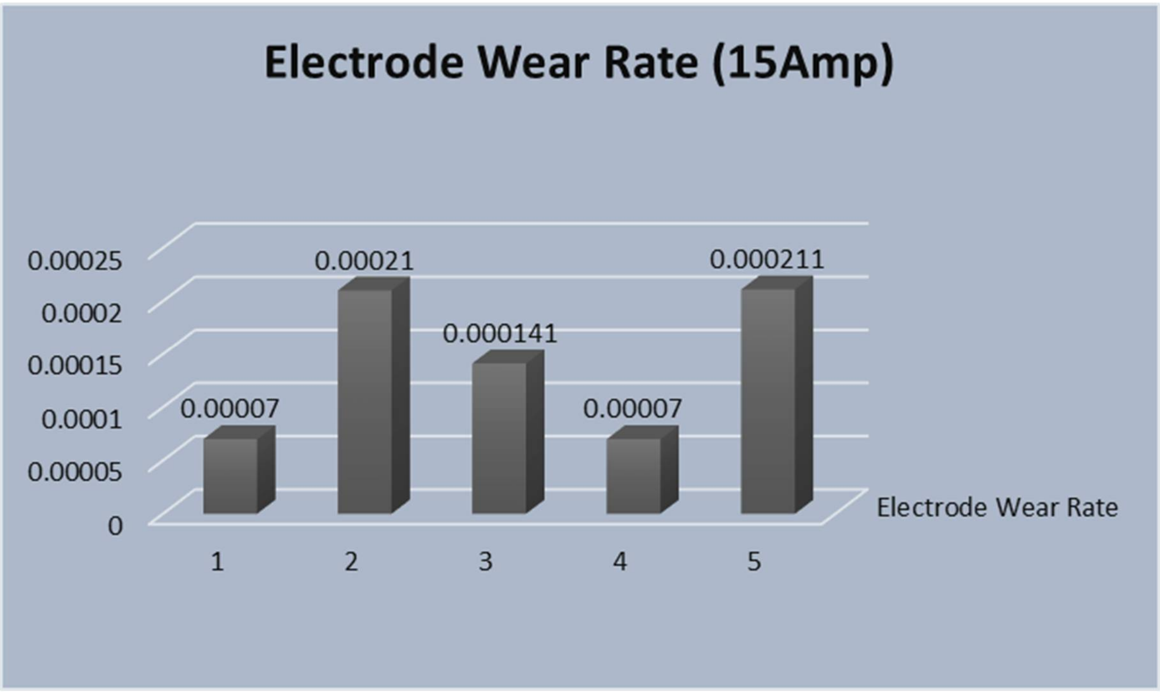

Fig. 4.8C Variation of EWR using Copper Tungsten electrode at 10A

4.9 Discussion

4.9.1 Effect of Pulse Current on Electrode Wear

Electrode wear is mainly due to high density electron impingement generated during machining from work and electrode materials. The electrode wear vs pulse current for SS-304 material is shown in Figure 4.9.1A. Copper Chromium Zirconium has the highest EW of 0.001428 g/min as against 0.001296 g/min for Beryllium copper and 0.000082 g/min for copper tungsten As the high density of electron impingement occurs at workpiece and electrode material during electrical discharge machining causes electrode wear. The electrode wear vs pulse current for SS- 304 material is shown in Fig. 4.9.1A. The EW of copper tungsten is very low when compared with other two electrode materials because of its high resistance to spark.

Copper Chromium Zirconium has the highest electrode wear. Copper tungsten shows least amount of electrode wear. As the melting point of other electrode is low electrode wear increases as the pulse current increases. Copper tungsten has less electrode wear because of its high melting point.

a. **Effect on Copper chromium zirconium electrode**

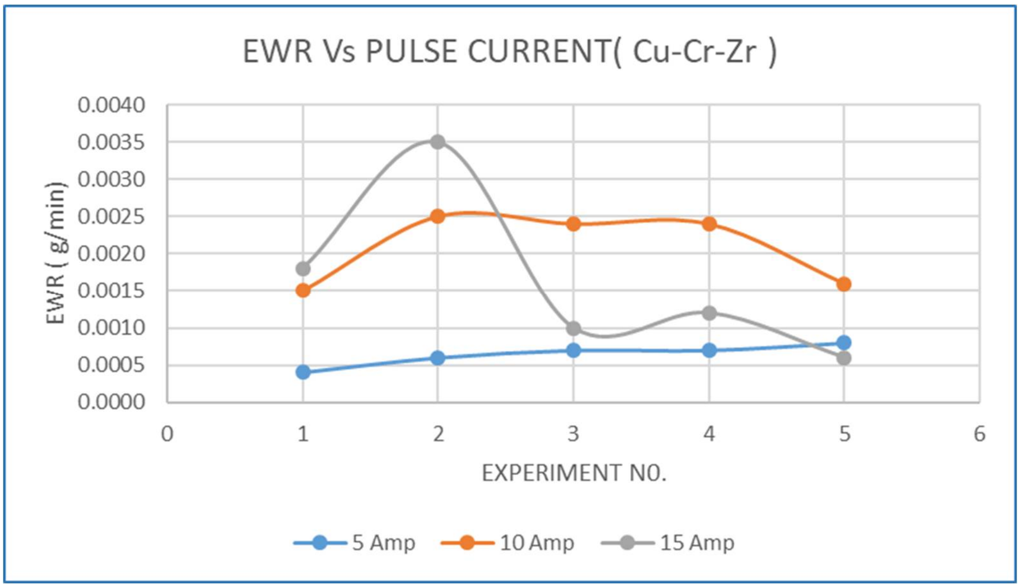

Fig. 4.9.1A Variation of EWR Vs pulse current

b. Effect on beryllium Copper electrode

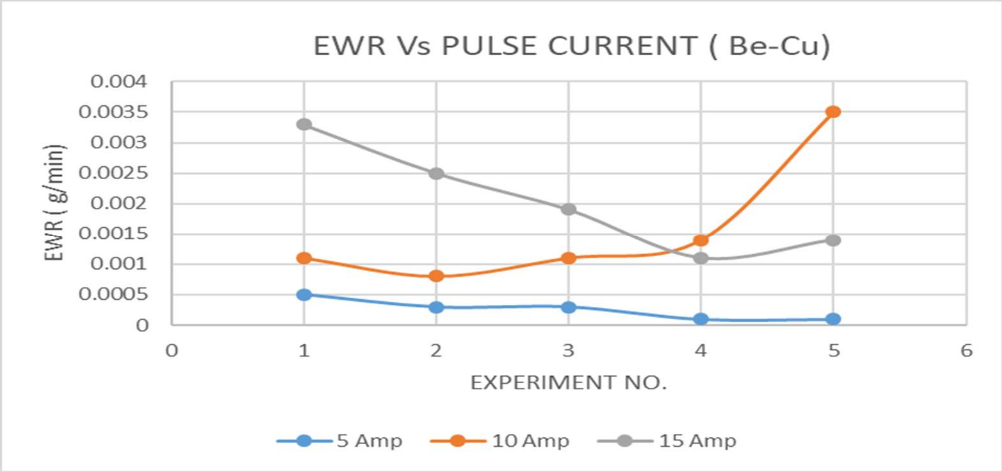

Fig. 4.9.1B Variation of EWR Vs pulse current

c. Effect on Copper tungsten electrode

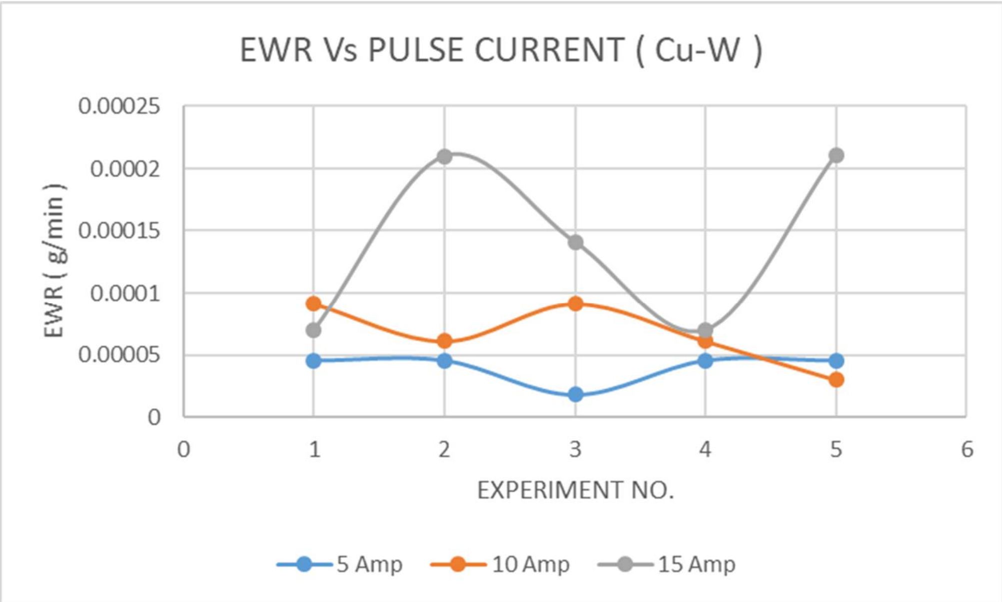

Fig. 4.9.1C Variation of EWR Vs pulse current

Copper tungsten also has the property to resist spark which is responsible for less electrode wear as compare to Brass and Copper electrode.

4.9.2 Effect of electrode tool material on Electrode Wear Rate

A set of experiments are performed on stainless steel - 304 work pieces with the use of different composite material electrode in Electric discharge machining. The experimental studies are conducted by varying the parameters like Current, Voltage and Pulse on time. The result shows that electrode tool materials have significant effect on electrode wear rate.

Effect of Copper chromium zirconium electrode- Copper Chromium Zirconium has the highest ELECTRODE WEAR of 0.001428 g/min. We can investigate the difference of electrode mass before and after machining.

Fig. 4.9.2A Electrode wear of copper chromium zirconium electrode

Effect of beryllium Copper electrode-. Beryllium copper is a ductile, weldable, and machinable alloy. Like pure copper, it is resistant to non-oxidizing acids like hydrochloric acid and carbonic acid. Electrode wear, which occurs on the surface can be investigate the difference of electrode mass before and after machining. Shown in fig. 4.9.2B

Fig. 4.9.2B Electrode wear of Beryllium copper electrode

Effect of Copper tungsten electrode- Copper–tungsten electrode was designed in order to combine the best properties of copper (high electrical and thermal conductivities) and tungsten (high melting point), achieving a low wear electrode. Electrode wear, which occurs on the surface can be investigate the difference of electrode mass before and after machining. Shown in fig. 4.9.3C

Fig. 4.9.2C Electrode wear of copper Tungsten electrode

The experiments were carried out for 2 mm depth of cut with three pulse current settings of 5A, 10A and 15A by copper tungsten, copper chromium zirconium and beryllium copper electrode to investigate material removal rate and electrode wear rate as a performance factor.It can be easily understand by graph shown in fig. 4.9.2D and fig. 4.9.2E

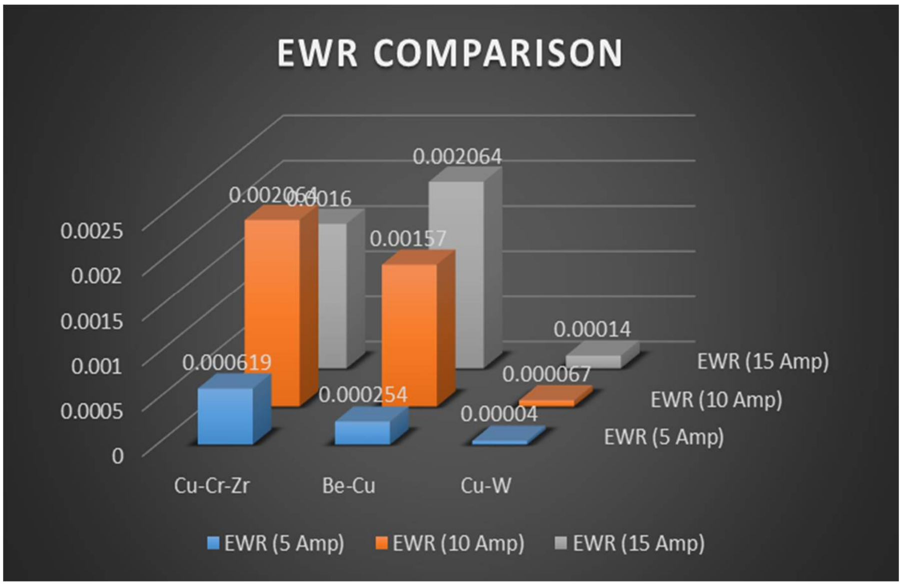

Fig. 4.9.2D Electrode wear rate comparison

The results of the present work reveal that proper selection of electrode tool materials will play a significant role in Electric Discharge Machining.

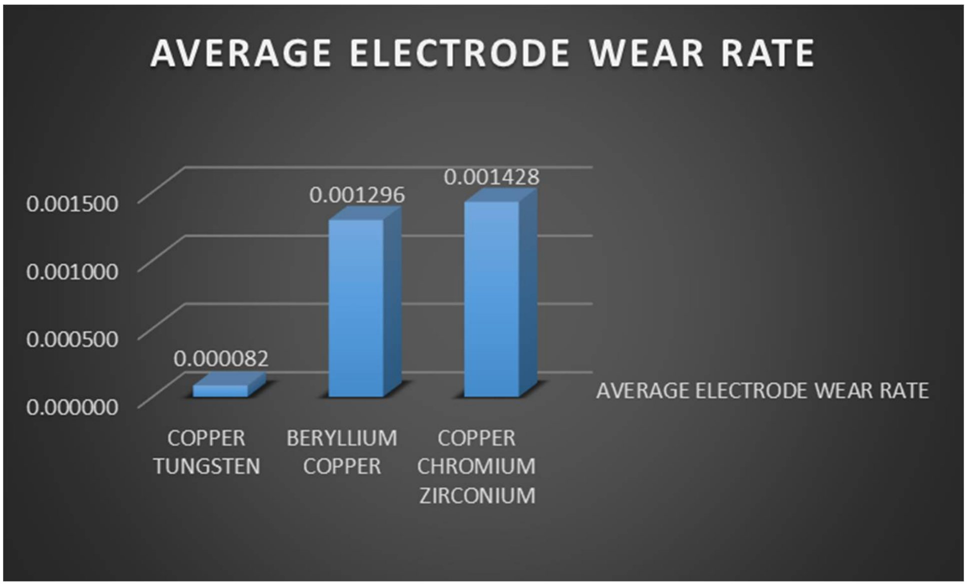

Fig. 4.9.2E Average Electrode wear rate

CHAPTER – 5

CONCLUSIONS

This project work investigates the performance of copper chromium zirconium, copper tungsten and beryllium copper electrode on machining characteristics of stainless steel 304 in the electrical discharge machine (EDM) die sinking. An experimental study has been conducted to investigate the effect of electrode materials on machining characteristics in EDM for Stainless Steel-304 using different electrode. Present investigation explores about the Electrode Wear Rate of the tool electrode. The experiments were carried out for 2 mm depth of cut and three pulse current settings of 5A, 10A and 15A. The following conclusions have been drawn from the experimental procedure. It can be seen from the collected data that all the controlled parameters i.e. current, pulse on time and servo voltage with pulse off time as a constant affects TWR. Main effect plots and interaction graph were drawn which shows relationship among the collected data

1. The effect of machining parameters on electrode wear rate (EWR) during electric discharge machining is strongly affected by **TOOL ELECTRODE MATERIAL**.

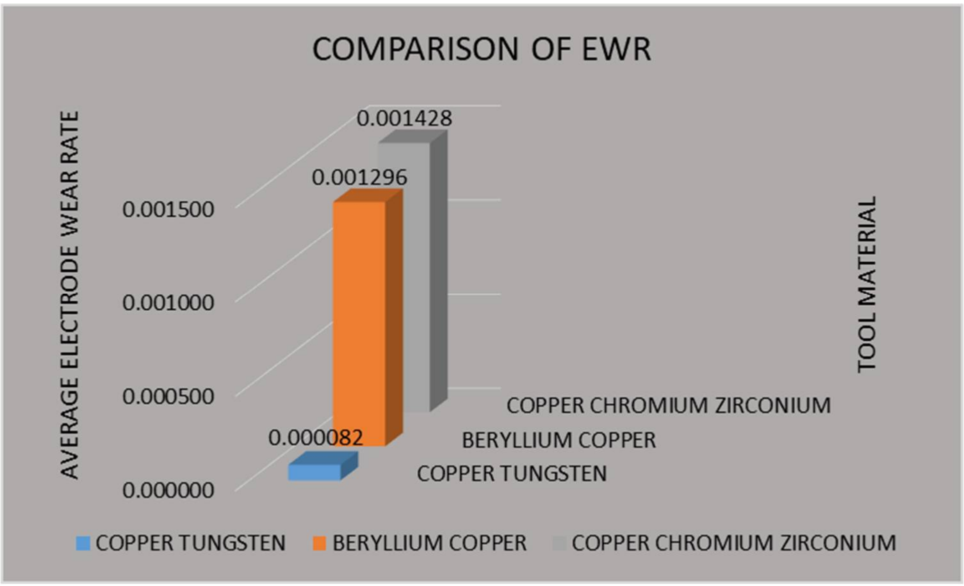

Fig. 5.1 Comparison Electrode wear rate

2. EWR (electrode wear rate) during electric discharge machining is strongly affected by **pulse current** while the pulse on time and servo voltage has least effect on EWR.

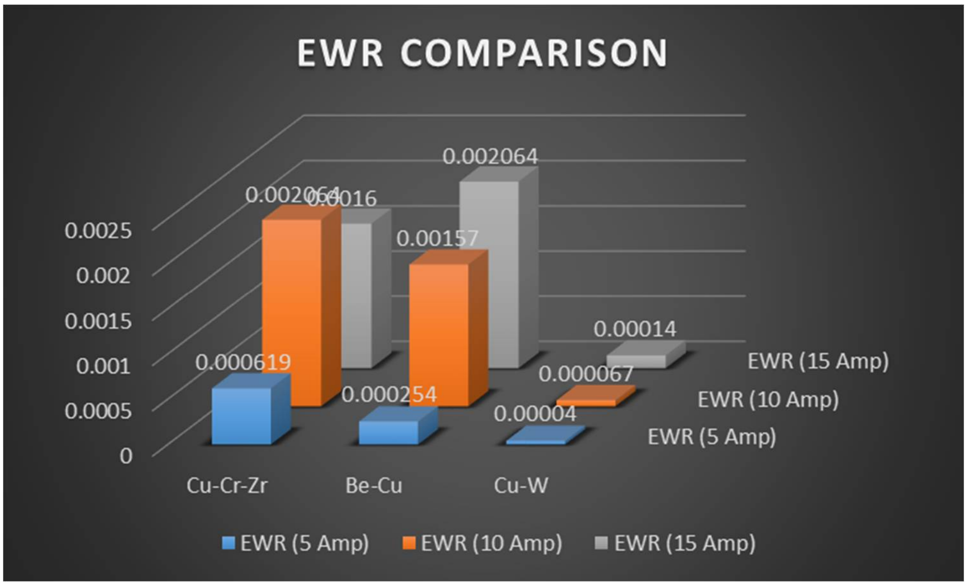

Fig. 5.2 Electrode wear Vs pulse current

3. The less electrode wear ratio (EWR) will make the machining performance better. From this experiment, the best selection electrode for electrode wear ratio (EWR) is copper tungsten (0.000082 g/min) followed by beryllium copper (0.001296 g/min) and copper chromium zirconium (0.001428 g/min). Table. 5.3 & Fig. 5.3 Represent the electrode wear rate for stainless steel – 304 using different electrode.

Table. 5.3 Data of average electrode wear rate

S.No.	Electrode Material	EWR at 5A	EWR at 10A	EWR at 15A
1	Cu-Cr-Zr	0.000619	0.002064	0.0016
2	Be-Cu	0.000254	0.00157	0.002064
3	Cu-W	0.00004	0.000067	0.00014

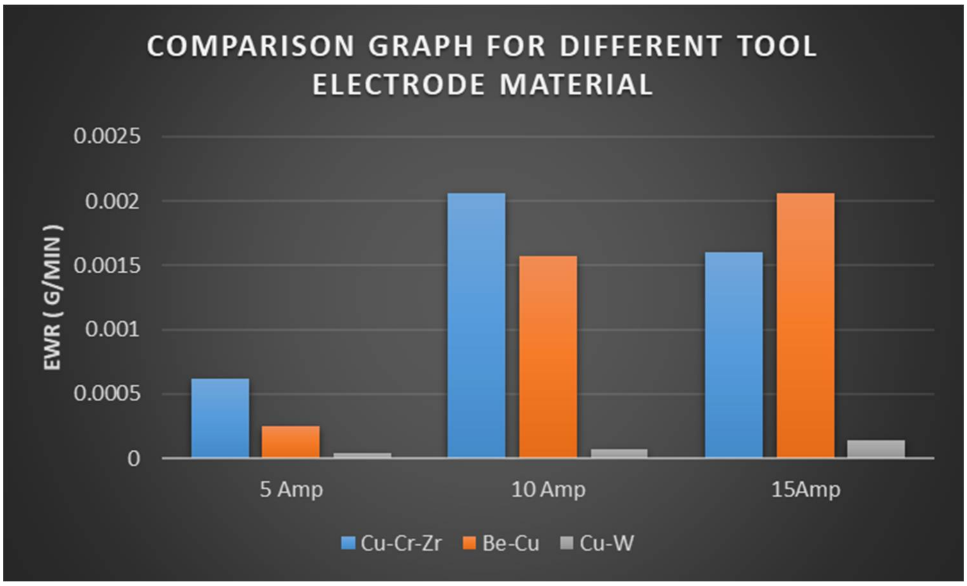

Fig. 5.3 Comparison graph for different tool electrode

4. Through this experimental procedure it has been observed that there is a corner wear in all electrodes during electrical discharge machining of workpiece. Fig. 5.4 shows the corner wear in copper tungsten, copper chromium zirconium and beryllium copper electrode.

Fig. 5.4 Corner Electrode wear

5. In copper tungsten electrode, least amount of electrode wear occurs and there is very low corner wear in the electrode. Fig. 5.5 explains about the electrode wear of copper tungsten tool electrode.

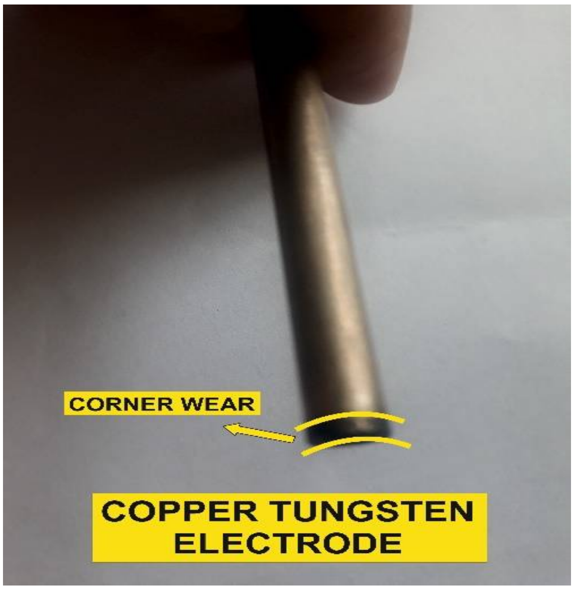

Fig. 5.5 Corner Electrode wear in copper tungsten

6. Maximum corner wear occurs in copper chromium zirconium electrode during electrical discharge machining of SS-304 work piece. Fig. 5.6 explains the corner wear in copper chromium zirconium electrode after machining.

Fig. 5.6 Corner Electrode wear in copper chromium zirconium

7. It is also observed that the thermal conductivity of electrode material plays a major role in electrode wear. Copper tungsten electrode undergoes less wear compared to copper chromium zirconium, beryllium copper because higher thermal conductivity facilitates rapid heat transfer through the body of the electrode. It is also observed that the higher melting point of electrode material will lead to the lower electrode wear.

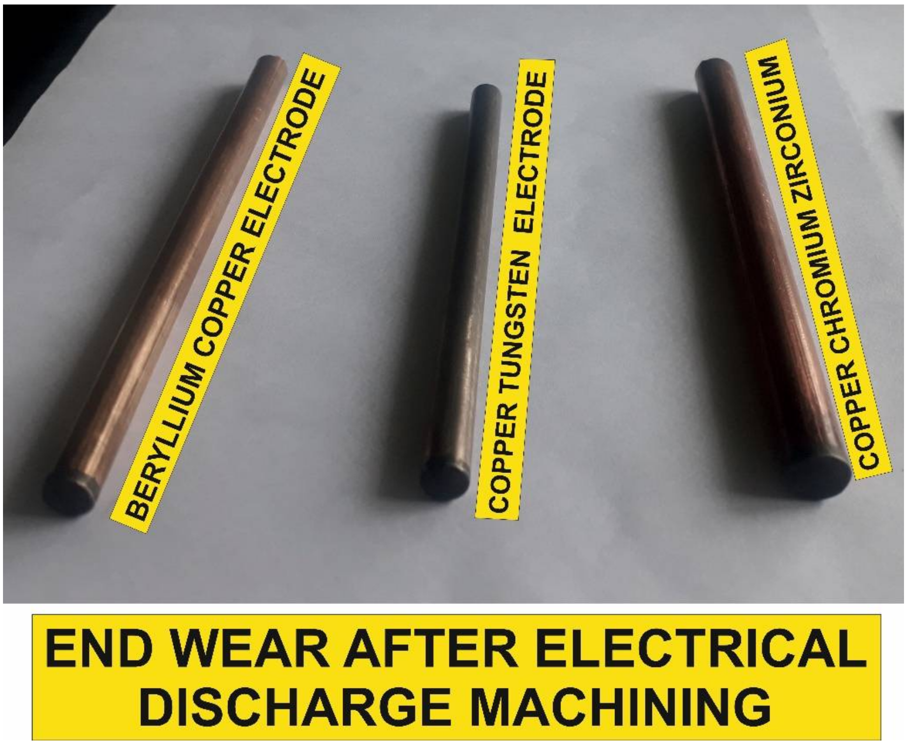

Fig. 5.7 Electrode wear in different electrodes

8. An experimental study has been conducted to investigate the effect of electrode materials on machining characteristics in EDM of corrosive resistant stainless steels 304.We can conclude that the prime requirement of any electrode material is that it must be electrically conductive and maintain less electrode wear. The materials best suited should have a very high melting point and a very low resistance to electricity. The selection of particular electrode material depends primarily upon the specific cutting application and upon the material being machined.

CHAPTER – 6

SCOPE FOR FUTURE WORK

This project work investigates the performance of copper chromium zirconium, copper tungsten and beryllium copper electrode on machining characteristics of stainless steel SS-304 in the electrical discharge machine (EDM) die sinking. The relationship between the machining parameters such as peak current, voltage, pulse-on time, and pulse-off time on machining characteristics was studied. The EDM process has a very complex nature due to the complicated discharge mechanisms and their interactions and this makes it difficult to globally optimize the process. The advent of new materials always makes parameter optimization a vast research area. The study can be extended by considering more number of parameters. Responses in machining of other materials with similar machining characteristics can be calculated and can find most suitable optimum parameter combination. Future work can be defined as following: -

1. Electrode tool cooling methods. Electrode tool cooling is another research field of potential benefit. Cryogenic cooling of electrode tool has provided positive results in terms of reduction in TWR (TOOL WEAR RATE).

2. Use of different electrode tools. Researchers can investigate the performance of the EDM process by using electrode tools of different materials, shape, size and geometry. Use of tubular electrode tools is in its infancy but has already provided promising results, it requires further attention.

3. Powder mix EDM. Powders of different materials mixed with dielectrics have been shown to improve the machining process. This is another area which requires further attention and researchers need to address the machining of different stainless steel grades using different EDM processes with dielectric fluids containing different material powders.

4. The EDM process hybridized with other processes can provide better results than EDM on its own. Magnetic force assisted EDM, laser assisted EDM and so forth, have the potential to overcome many process limitations. For example, ultrasonic assisted EDM showed significant improvement in performance. Research trends may be directed toward the combination of several processes.

5. Most of research work in EDM relates to use of 3D form tool. Alternate types of tools like frame type and plate type are yet to be tried for more work-tool interfaces.

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