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A Review on studies of Powder Metallurgy tool electrodes and cryogenic treatment in Electric Discharge Machining

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Abstract

Electrical discharge machining is a non-traditional method for material extraction. Removal of material takes place without any contact between the workpiece and the tool. Conductive materials that possess high hardness and difficult to machine can be machined by electric discharge machining. Deep, intricate and precise shapes can be produced using spark erosion. Spark is generated between the submerged cutting copper tool and component, which further transforms into a plasma channel. However, this process faces some challenges regarding low MRR, surface roughness, and tool wear. Researchers have developed some means to reduce the impact of these parameters on the machining method, such as a tool made by powder metallurgy and cryogenic operation of workpiece and tool. This paper reviews the research work done in the field of EDM tool made by powder metallurgy, cryo-treatment of tool, the effect of process parameters on machining and optimum parameter setting for best response characteristics.

Keywords— *EDM, MRR, TWR, P/M electrode, Cryogenic treatment*

I. INTRODUCTION

Electric Discharge Machining is a thermoelectric machining process which is a type of non-conventional machining processes. These processes are called non-conventional because these processes do not use conventional tools (turning tool, shaper tool, milling tools, form tools) directly. Still, as a substitute, use the indirect energy form; for example, energy can be mechanical, chemical, electrochemical or thermoelectric. EDM is beneficial in precision machining, die cavity and producing complex shapes.The concept of machining with spark erosion is not new. Its origin dates back to the 18th century. In the year 1770, Joseph priestly, an English scientist, was the first to find that electric sparks cause erosion. In the 20th century year 1943, two Soviet scientists Dr. B.R Lazarenko and Dr. N.I. Lazarenko discovered that the spark erosion could be controlled if the electrodes are submerged in a dielectric liquid. From their invention in 1943 to CNC EDM, a lot has changed in the region of EDM. But

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there are a lot of challenges in this process. This process is useful in machining hard conductive material, which otherwise cannot be machined by any other means. The main difficulties in the EDM process are tool electrode wear, low MRR considerable operation time, surface amendment and surface roughness. As stated earlier, EDM is a thermal erosion process. The job or the workpiece needs to be conductive to be machined at the EDM machine. The removal of material from the job is achieved through restricted electric sparks between the two electrodes. The shape of the tool electrode is the same as the final workpiece. Die-sink EDM is a variant of the EDM process. Other includes wire cut EDM.

A typical EDM set consist of the following parts-

A. Workpiece

It is the material to be machined. The workpiece needs to be electrically conductive to be processed at EDM. It is generally made anode.

B. Tool Electrode

Tool electrode or only tool is manufactured by a material which has high electrical and thermal conductivity as well as high hardness and melting point. It is generally made cathode.

C. Servo System

The servo system is used to control the vertical movement of the tool electrode while machining.It works by receiving signals from the gap voltage sensors.

D. Dielectric Medium

The dielectric medium is necessary for spark production. EDM tool and workpiece both are immersed in the dielectric fluid. Dielectric fluids are electrically insulating, and these provide an oxygen-devoid environment. It helps in creations of plasma channel by ionizing; it gives the flushing effect means to take away the material removed from the workpiece, and it helps in heat transfer, provides a cooling effect to both electrodes.

E. Power Source

This unit converts the AC from the core power supply into a pulsed direct current, which is used for the generation of spark.

F. Pulse Generator

This unit provides pulsating voltages and current for a particular expense of time.

In Die-sink EDM, the material going to be machined is placed inside the dielectric liquid. Mostly, the tool is made cathode, and the work piece as an anode. No contact between the two electrodes is permitted. As the voltage between the two electrodes is applied, the cathode

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is made to move towards the workpiece, thus, at some distance achieving the breakdown voltage of the dielectric. At this point, the electric field between the electrodes is so increased the current starts flowing between them. A stream of electrons from the cathode collide with the atoms of the dielectric breaking it into ions; this is called ionization of the dielectric. This ionization causes the formation of a plasma channel amid the electrodes. The electrons and ions hit the surface of the anode or workpiece, which is visualized as sparks. The heat from the striking of electrons and ions melts and vaporizes the surface of the workpiece resulting in material removal. The material which has been extracted from the job by melting and vaporization is sieved away by the continuous circulation of the dielectric fluid. In EDM, the MRRs are meagre.

Again the same cycle starts for the machining process. The dielectric fluid needs to recirculate as the process goes on because regular flushing of removed material is required from the machining zone or area. If the eroded material stays in the machining area, then it enhances the electrical conductivity of the dielectric, which results in a wild spark discharge. This may result in decreasing the MRR and wild discharges leads to poor surface quality, more wear of the tool electrode. After the pulse is of the new dielectric from the surrounding area replaces the ionized particles of the dielectric. Some of the working factors of the EDM process are polarity, pulse up time, pulse down time, discharge current, maximum current, gap voltage and the average current. Major output parameters of Electric Discharge Machining are MRR, tool wear, surface texture, recast layer thickness, tool wear ratio and overcut. EDM process faces some challenges in terms of low MRR, tool wear, and surface roughness. Due to high-temperature, some portion of the tool electrode also gets melt, and positive ions from dielectric and workpiece impinge on the tool surface and remove the material from the tool.

EDM tools which are made by conventional machining lack in strength and refractory abilities. Powder metallurgy is a process in which parts are produced from metal powder. Any complex and intricate shapes can be produced by powder metallurgy dies. Compaction pressure and sintering temperature are two main factors that decide the properties of the final product. This process is economical as compared to the conventional method for producing complex shapes. The cryogenic treatment can improve the hardness and conductivity of the various parts. Cryogenic treatment is the method of dealing with shallow temperature ranging between -150 ℃ to -273.15 ℃. Cooling the materials to low temperature helps in increasing the mechanical and electrical properties of the materials. In this method, the part is

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submerged in the liquid nitrogen for a definite period. This process has three stages first is cool downstage, soaking stage and warming stage. Cryogenic treatment increases the hardness of the workpiece by converting the amount of retained austenite into hard martensite. Cooling to cryogenic temperature helps in the formation of η-carbides, which fill the voids and cavities in the structure and make the material denser. The cryogenic treatment makes the structure uniform and improves conductivity of a job. The main focus of the researchers in EDM is to increase the MRR, lower the tool wear rate and to refine the surface finish. An increase in tool wear decreases the tool life and can increase the overall cost of machining.

LITERATURE REVIEW

This review is from findings of various researchers about electric discharge machining, EDM electrodes made by powder metallurgy, and on the cryogenic treatment of the EDM electrodes and also the effect of these changes on MRR, tool wear, and surface roughness.

. Prakash *et al.* [1] used powder in electric discharge machining to machine a β-titanium alloy. This alloy has wide spread applications in biomedical implants. Tool electrode used was pure Titanium alloy and silicon powder used as additive in the dielectric. Surface micro-cracks were reduced and thickness of the recast layer also increased as the concentration of the silicon powder was increased for the same working conditions. Optimum concentration for best surface characteristics and machining efficiency was 4 g/l silicone powder. Samuel *et al.* [2] worked on electrodes made by powder metallurgy. They used electrolytic copper powder 99.7% pure for the making of tool and workpiece material was hardened steel. Increasing the compact pressure from 62 to 625 MPa showed an increases in the electrical, mechanical and thermal properties. Green strength increases, electrical resistivity decreases, and hardness of tool increases. Asperities on the surface of tool cause the reduction in the breakdown voltage. Low compacting pressure and low sintering temperature result in higher tool wear in EDM.

The work of Li Li *et al.* [3] consisted of using a powder metallurgy electrode of Copper 25%-Tungsten 75% (with Nickel 3.5% and varying proportions of the Titanium carbide). Main process parameter was the composition of titanium carbide. TiC increased the solubility of copper in tungsten. Relative density first increased and then decreased as composition varied from 5 to 50%.Tool wear first decreased and then increased. Proper densification was achieved at 15 % of TiC in the electrode. MRR was high at 15% of TiC

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similarly, tool wear was also low at 15% of TiC in the electrode. Yan *et al.* [4] worked on Chromium composites. Copper powder and chromium powders with a mesh size of 53 μm and 45 μm were used for making the composite. Low compaction pressure and low sintering temperature were used for making the tool electrode. MRR was high when tool electrodes made at pressure 20 MPa and 30 MPa were used. Surface quality was also poor in this case. Highest MRR was obtained with a tool made up of pure copper powder and zero chromium concentrations. Electrode wear rate was also high in case of pure copper powder and lowest MRR and EWR was achieved at Cu-Cr ratio of 57%-43% because the addition of chromium powder increases the corrosion resistance of the electrode. Corrosion resistance of the workpiece also increases because during machining Cu-Cr particles migrate from the workpiece to the electrode.

Puertas *et al.* [5] used conductive ceramics. Boron carbide, SiC, and WC were used as a component to be machined and electrolytic Cu as a tool material. It was found that surface roughness increased with increase in current intensity in case of SiC and WC but decreased in case of boron carbide. Surface topography also degrades with increase in the value of pulse on time and raising the duty factor worsen the surface of SiC but effects were opposite for boron carbide. With longer duty cycles the tool wear rate was increased in case of boron carbide and SiC but in case of WC, it get decreased after reaching a maximum value. A comparison study was done by Singh *et al.* [6] among responses received from Copper, Copper-Tungsten, Brass and Aluminium electrodes. It was found that Copper and Aluminium electrode offered highest MRR trailed by Copper, Tungsten and Brass. Copper electrode showed a constant diametrical overcut with the intensification of the discharge current. Aluminium also displayed least overcut. Electrode wear rates were low with Copper and Copper Tungsten electrodes. While Brass electrode exhibited more wear than any other electrode. In case of surface roughness, Copper Tungsten gave low values at high discharge currents. Aluminium gave rough surfaces at lower current values. Brass also provided a good surface with at higher discharge current Copper and small increase in roughness as current approached to higher values.

Surface modification using powder metallurgy electrodes was studied by the S. K. Ho *et al.*[7] powder metallurgy Copper electrodes were prepared at compaction pressures of 15 MPa, 32MPa, and 300 MPa. It was found that thicker RL (recast layers) were achieved using the straight polarity where thickness variation was from 4-11 μm. Using hard Copper electrode with negative polarity increased the hardness of the recast layer up to 3 times than

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with straight polarity with powder metallurgy electrodes. Reverse polarity was found suitable for surface alloying because using a tool with positive polarity to cut a component with less value of thermal conductivity was easy because the heat energy of the discharge performed mainly on the electrode. This reason united with the weaker bonding of atoms of powder metallurgy electrode provided more alloying. Positive polarity resulted in higher surface roughness. The powder metallurgy electrodes gave more alloying than the solid electrode. Electrodes prepared at 32 MPa provided better alloying characteristics than others.

Beri *et al.* [8] used a Copper Tungsten electrode fabricated using PM process and a solid Cu electrode. Copper electrode helped in attaining maximum MRR. Copper -Tungsten electrode gave minimum surface roughness. Best parameters for Cu electrode were 10.4-ampere current, 0.67 duty cycle, and 0.71kg/cm^2 flushing pressure for MRR. For surface roughness in case of Copper-Tungsten optimum parameters were electrode 4.5-ampere current, 0.50 duty cycle, and 0.3kg/cm^2 flushing pressure.

A WC –Cobalt workpiece which was made by powder metallurgy process was used by Kanagaranjan *et al.* [9] in their EDM experiment. Cobalt percentage was 30% and WC was 70%. Response surface methodology was utilized for establishing the relationship between the process parameters and the desired factors. It was found that the combination of a low pulse on time, high maximum current, high rotational speed, and high flush pressure resulted in increasing the MRR and decreasing the surface quality. An error of 5 percent was observed between the practical value and the anticipated value. MRR was found directly proportional to the quantity of cobalt because cobalt has higher thermal conductivity as compared to tungsten and it was easily removed.

Pathak *et al.* [10] fabricated a new tool using Zirconium diboride (ZrB_2) and varying composition of Copper. Pallets were fixed with a Copper rode using silver paste. Maximum hardness of the composite was at 30% Cu addition because of uniform accumulation of Copper and above it, hardness decreased. MRR was found highest at 40% Copper addition. Tool wear rate increases with increase in Cu%. The composite tool showed less wear as equated to the pure Copper tool. Presence of Zirconium diboride particles in Copper matrix increased the wear resistance. Surface roughness was more in composite tool than the Cu tool because of higher MRR.

Recast layer characteristics were studied by Patowari *et al.* [11] using a Copper-Tungsten electrode on C-40 steel. Tungsten copper compacts were made at different compaction and sintering temperature. Best results were obtained at composition 75%-25%

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of Tungsten-Copper. The recast layer was having a variable thickness from 3-785 μm. In the layer, there was the presence of Copper, Tungsten and WC. The range of microhardness value was from 9.81 -12.75 GPa. With a higher pulse on settings thicker layer was deposited. The optimized parameter settings for the solidified layer were composition tungsten 75%-copper 25%, compaction pressure 120 MPa, sintering temperature 900°C, maximum current 8-ampere, pulse on time 48 microseconds, and straight polarity.

Nadilman *et al.* [13] made an EDM tool using powder metallurgy process. Copper powder 99% pure of 200 mesh and TaC (Tantalum Carbide) powder 99.9% pure of 200 to 325 mesh was used. Main elements which decide the aptness of the electrode for the EDM were electrical conductivity, thermal conductivity, and density. By raising the TaC composition, electrical conductivity of the electrode was decreased. The thermal conductivity of the green compact electrodes was little high than the sintered ones. Under sintering condition, the electrodes cannot be used because of the low conductivity.

Singh *et al.* [14] have seen the effects of the pulse-on time and the pulse-off time on the machining of AISI D3 steel. Tool electrodes used were Brass and copper. Using Copper electrode maximum MRR was recorded at pulse on time 50μs.Using Brass electrode MRR increased when the pulse on time was increased from 50 to 100μs.Increase in pulse off time from 15 to 20μs increased the MRR for both Cu and Brass. Because the increase in pulse off time gave enough time for dielectric fluid to remove the molten debris from the spark area and also provided enough time for fresh dielectric fluid to reach the area. Increase in pulse on time from 50 to 100 μs in case of copper resulted in a decrease in MRR because more molten debris present in the area from the previous spark lead to an uncontrolled spark which in turn reduces the Material Removal Rate.

Yusoff *et al.* [15] examined the effect of sintering parameters on the microstructure and properties of the copper-WC composites. The process parameters were sintering temperature 800 to1000°C, compaction pressure 300 MPa. Density was increased from temperature 800°C to 950°C and after 950°C it started decreasing. Hardness increased till 950°C and after a further raise in sintering temperature lead to downgrade hardness because of the grain growth of Copper started. Electric conductivity was also improved by increasing the sintering temperature from 800°C to 950°C.This was due to the elimination of the pores at high temperature. F. klocke *et al.* [16] focused their work on the analysis of removal of material and tool wear with the aid of graphite electrodes. Tool material were five different graphite electrodes each having a different grain size. Graphite electrodes integrate some of

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the oil volumes into themselves due to their porous nature. MRR was increased with the intensification of the pulse current. By increasing the pulse duration, MRR was declined. Negative tool wear also occurred which means that material from workpiece got deposited on the tool.

Mohan *et al.* [17] used WC and Brass electrodes to study the outcome of tool electrode resolidification on the surface hardness. The results revealed that the higher melting point of the tool electrode will cause more thickness of recast layer. Thus workpiece machined with WC has higher surface hardness, than the original because of the high hardness of WC tool. There was an increase of 80% in the hardness of the top layer of the machined workpiece as compared to the unmachined workpiece and brass tool formed a soft layer on the machined surface whose hardness was 60% percent less than the original workpiece. +ve-polarity area takes more thermal energy than negative one. Thus when the tool is made positive more tool particles get melted and get deposited on the machined surface thus increases their concentration in the recast layer. The effect of EDM process parameters on tool wear were studied by the Kumar *et al.* [18] Tool wear was decreased with increase in pulse on time because spark energy gets increased with a pulse on time which leads to a wider plasma channel thus heat transfer between the workpiece and dielectric get increased. Increase in gap voltage led to decrease in the tool wear rate.

Tijo D. *et al.* [19] performed surface modification of the Al using EDM using green compacts electrodes of Cu-W. Tungsten from tool formed WC due to reaction with the carbon content in the dielectric fluid. This WC gets collected on the workpiece surface along with the Cu. Lower compacting pressure, higher peak current, and pulse on time backed both deposition rate and wear rate of tool. But when the pulse on time was increased from 200µs to 300µs then tool wear rate and deposition rate both decreased.. Kumar *et al.* [20] studied the results of U-shaped Copper electrodes on the overcut. As the thickness of the electrode increased the sparking area also increased which increased the overcut.

Tool wear rate of two different electrodes was studied by [21] Mathew *et al.* used a powder metallurgy Copper (75%)- tungsten(25%) and a solid Copper electrode. It was found that for PM electrode the tool wear rate was decreasing relentlessly with increase in maximum current. For the conventional electrode tool wear rate was decreasing till 50 V but with further increase in voltage it started increasing and same results were shown by the PM electrode. By increasing the duty cycle, TWR for conventional electrode decreased. PM electrode showed better tool wear rate than the conventional electrode. TWR increased with

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increase in duty cycle, gap voltage and maximum current. Sharma *et al*. [22] used Copper and Brass electrodes with internal flushing to machine AISI 329 stainless steel. They used Taguchi and grey relation theory to identify the best set of process parameters. High MRR and low TWR were achieved in case of the Copper electrode for the same set of parameters. Best settings for the machining of workpiece were with a copper electrode, pulse current 5A, pulse on time 9 μs, pulse off time 2μs and flushing pressure 80 kg/cm^2. Electric discharge alloying was used by Gill *et al.* [23] to modify the surface of high carbon EN-31 steel. A electrode of Copper-Chromium-Nickel was fabricated using powder metallurgy techniques. Microhardness of the workpiece increased by an amount of 139.7%.

Moudood *et al.* [24] used assisted electrode method to machine Al_2O_3 , ceramic. A Copper foil was applied over the surface of the workpiece. During the machining, the spark was initiated by the assisted electrode after this a continuous conductive carbon layer was formed on the surface of the workpiece which helped in further machining. Material removal occurred due to the thermal load generated by each spark also called spalling. Melting and vaporization also helped in material removal. It was found that the workpiece can be machined with gap voltage between 12-14 V, maximum current 1.1 A, pulse on and off time at 8μs. Beyond the range of gap voltage, the material cannot be machined because past this range conductive carbon layer cannot be formed. Results also showed that the workpiece cannot be machined with a copper tool having straight polarity.

Patowari *et al.* [25] they studied the surface integrity of the C-40 steel workpiece by machining it with electrodes made by powder metallurgy process. Tool electrode was from tungsten-carbide (60%) and copper (40%). Electrodes were prepared at pressure 180, 240, 300 and 360 MPa. It was found that compacts which consist of more than 60% of WC were unable to bind and form a complete shape. Green compacts provided more wear rate than the fully sintered electrodes because of the loose bonding between the particles of green compact but this characteristic helped in easy transfer of material to the workpiece surface. As a result of the material transfer, a RL was formed on the tool's surface which contained particles of WC, Cu, and Fe. At lower values of maximum current and pulse on time the recast layer was smooth and thin but at high maximum current and pulse on time surface of the layer was rough and thickness was more. Compacts which were made at high compaction pressure showed low MRR and low TWR.

Cogun *et al*. [26] examined the surface integrity of the workpiece using various electrodes made by powder metallurgy process. Tool electrodes used were Cu-B_4C with

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proportions 80%-20% respectively, a pure Cu electrode both made by powder metallurgy and a solid electrolytic Copper electrode. Their results showed that the electrodes which were having a resistance equal to 1 ohm or more cannot start the machining process. The workpieces which were machined by Cu-B_4C electrode displaced hardness 4-4.3 times high and abrasive wear resistance 65% to 78% lower than the original workpiece. Solid Cu electrode provided highest MRR and Cu-B_4C gave the minimum. Surface roughness value in case of a workpiece machined by solid Cu electrode was minimum equal to 2.6μm and was maximum in case of the Cu-B_4C electrode with a value of 5.3μm. Average recast layer thickness for the three electrodes was 3 to 9 μm. B_4C, FeB, and Fe_3C were found in the recast layer of the workpiece machined Cu-B_4C. In case of Cu and PM Cu electrodes alpha Fe, CuO and $FeCu_4$ were found. These compounds increased the hardness and abrasive resistance of the job.

Ryota *et al.* [27] worked on powder mixed EDM. Chromium powder was blended in the cutting fluid. After the experiments in the results, it was found that a recast layer was formed containing a concentration of Chromium. Chromium content in the layer increased with increase in powder concentration and decrease in discharge current. Three different types of electrodes were used by [28] Payal *et al.* They were solid Copper electrode, graphite electrode and Cu-W electrode. With the increase in pulse on time, MRR also increased because with the increase in pulse on time more energy was discharged with each spark which led to increased MRR. Graphite electrode provided maximum MRR followed by Cu electrode and then Cu-W electrode. Tool wear decreases with an increase in pulse on time because longer pulse duration helps in heat dissipation from tool to workpiece. Graphite tool gave maximum TWR followed by Cu and least TWR was provided by Cu-W. Jeykrishnan *et al.* [29] used a Copper electrode with coating of nickel. Surface roughness of the workpiece was greatly affected by the discharge current. Increase in current at shorter pulse duration resulted in regular sparks which contributed to smooth MRR but with longer pulse duration spark energy got increased thus craters with bigger sizes formed on the surface of workpiece thus reducing surface roughness. The optimum parameter setting for the surface roughness were at highest discharge current 50A, at minimum pulse on time 45μs and at maximum pulse off time of 16μs.

Goyala *et al.* [30] the aim of their study was to analyse the surface properties of a workpiece after machining it with the electrode made by PM process. Tool electrodes were made from Cu and Manganese powder of different compositions and a solid Copper electrode

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was also used for comparing the results. Electrode with composition 70-30 of Cu-Mn provided the maximum microhardness as compared to the electrode with 80-20 of Cu-Mn composition. As the maximum current rose from 4A to 8A the microhardness increased for all materials. This is because Mn from the tool gets deposited on the work surface forming a recast layer. Surface roughness was minimum for the copper electrode. And for both the electrodes made by PM it is slightly equal. The reason was the porous nature of the composite electrodes. Surface roughness increased with increase in maximum current and pulse on time. Sarfraz *et al*. [31] used various dielectric fluids to study their effect on MRR and TWR. Water and the kerosene were used as a dielectric medium. Discharge current and pulse on time were used as process parameters. The research concluded that higher current and pulse on time leads to higher MRR. Because of arcing (due to decomposition of water molecules) MRR in water as a dielectric medium was less than kerosene. Electrode wear was less in kerosene because during machining carbon from kerosene get deposited on the electrode which acts as a protective layer. On the other hand in case of water, oxide layer get deposited on the tool which breaks easily on a lower temperature. The surface of a workpiece machined with kerosene was smoother than one machined with water. So kerosene was preferable over water.

Meenakshi *et al.* [32] used cold treated and cryogenically treated Copper electrodes. The compact structure of copper obtained after DCT reduced the electrical resistivity of the Copper electrode. Cold treatment was done at -150°F and cryogenically treatment was done at -300°F. MRR was increased by 12.09% when compared with non-treated electrodes. Cold treatment showed insignificant improvement as matched to non-treated electrodes. Electrode wear rate was reduced from 20.33% to 19.58% in case of cold treatment and 19.78 % in case of DCT. Thus the effects of cryogenic treatment in case of EWR rate were almost negligible. Liquid Nitrogen was used in the experiments by Suleiman *et al.* [33]. Tool material was Copper and the workpiece was a Titanium alloy Ti-6Al-4V. The liquid nitrogen was introduced through a hole in the Copper electrode at a temperature of -195℃. From the experiments, 27% reduction was achieved in electrode wear ratio. It happened because Nitrogen cooling helped in improving the thermal conductivity of the electrode which reduced the entrapped heat in the electrode which in turn reduced the vaporizing and melting of the electrode thus reducing the wear. In case of surface roughness highest 8% improvement was achieved by Nitrogen cooling. Current intensity and pulse on time have a

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bulging effect on surface roughness. Nitrogen cooling caused a reduction in vaporizing and melting of the electrode which results in smoother surfaces.

Rupinder Singh *et al.* [34] used various tools to study the response characteristics. Titanium, Copper, and Copper Chromium were selected as the tool materials. Cryogenic treatment of the tools were done at -80℃. From the results the optimized value for tool wear rate was obtained with 2A current, cryogenically treated workpiece and cryogenic treated Ti tool. Cryogenic treated Ti tool gave minimum TWR as compared to all other tools. The optimized parameters for MRR were achieved using a non-treated Titanium tool, non-treated workpiece and the current settings at 6A. Minimum surface roughness and the dimensional accuracy were achieved at the parameter setting same as for the TWR. Yildiz *et al.* [35] their work involved the cryogenic treatment of the workpiece. Pure copper was used as the tool electrode. Beryllium Copper was used as the workpiece material. Two different sets of cryogenically treated and non-treated workpieces were made. Cold and cryogenic treatment of the workpieces was done at -150°F and -180°F respectively and the soaking time for both cases was 8 hours. The electrical conductivity of Be-Cu workpieces was increased by 5% in cases of cold treatment and 13% in case of cryogenic treatment. The increase in MRR was about 20-30 percent in case of cold and cryogenic treated electrodes. The increase in MRR was related to the increased conductivity of cold and cryogenic treated workpieces.

The effects of cryogenic treatment on the shape retention capability of tool were studied by Srivastava *et al.* [36]. Discharge current and pulse on time were main factors which affected the shape retention. With the increase in discharge current, the out of roundness value was increased. By increasing the pulse on time, distortion of the tool was decreased. It was discovered from the experiments that the shape retention capacity of the cryogenically cooled electrode was better than the non-cooled. The out of roundness value for the cryogenically cooled electrode was less. Kumar *et al.* [37] performed cryogenic treatment in additive mixed electric discharge machining. With cryogenically treated electrode the tool wear rate and wear ratio both were found minimum because of the increase in wear resistance, refined grain structure, improved thermal and electrical properties due to cryogenic treatment at -193.15℃. Best parameter settings obtained for minimum tool wear rate were positive polarity, 2 mm retract distance without the powder, cryogenically treated tool, 150 microseconds pulse on time, 0.5A maximum current, 0.87 duty cycle, 40 gap voltage. The increase in the concentration of Graphite powder led to increased MRR.

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Srivastava *et al.* [38] studied the effects of cryogenic treatment on the electrode wear rate. As the discharge current increased, EWR was increased for both Cryogenic cooled and non-cooled electrode. It was found the use of liquid nitrogen reduced the wear by 20 percent. EWR get decreased with increase in pulse on time for both the electrodes. EWR increased with increase in discharge current keeping the pulse on time value same. EWR was less in case of the cryogenically cooled electrode. Increased duty cycle also led to increased EWR. Surface roughness also increased with increase in pulse on time because of more frequent sparks. In case of liquid nitrogen cooled electrode, the surface roughness was reduced by 27 percent as compared to the non-treated electrode. Mathai *et al.* [39] treated Copper tools cryogenically for 12 and 24 hours. Cryogenic treatment increases the hardness of electrodes. MRR for the non-treated electrode is higher as compared to cryogenically treated electrode. Jafferson *et al.* [40] worked on the cryogenic treatment of micro electric discharge machining tool. Tool materials were Copper, Brass, and Tungsten tubes. Tools were cryogenically treated till -185℃ and soaking time was for 36 hours. It was found that the TWR was decreased by 57% for Tungsten, 50% for Brass and 34% for Copper electrodes. MRR was decreased by 55% for Tungsten, 38% for Brass and 33% for Copper electrodes. Electrical resistance was decreased by 17.85% for Tungsten, 10.6% for Copper, and 4.4% for Brass electrodes. Microhardness values were increased by 120% for Tungsten, 93% for Brass, and 17% for Copper electrodes. The average crystallite size is reduced by 29% for Brass, 12% for Copper, and 5% for Tungsten electrodes.

Singh *et al.* [41] used cryogenic treatment on different types of electrodes. Tool materials were copper, brass and graphite electrodes. Tool wear rate in case of cryogenically treated electrodes is less as compared to non-treated electrodes. Reason being cryogenic treatment makes fine carbide particles and austenite is converted into more stable and hard martensite. TWR of copper was less as compared to other electrodes. MRR was increasing with increase in discharge current. Increase in discharge current leads to high energy strikes that lead to erosion of more material from the workpiece.

Kulwinder *et al*. [42] performed cryogenic treatment on Copper-Tungsten electrode. MRR increased with the increase in maximum current for both electrode, but MRR was found more with the cryogenic copper tungsten electrode as compared with the non-treated copper tungsten electrode. MRR showed a decrease with the increase in gap voltage from 40 to 50 volt and increased as voltage rises from 50 to 60. For cryogenic copper tungsten

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electrode MRR was increased with increase in gap voltage from 40 to 50 volt and then decreased with increase in gap voltage from 50 to 60 volts.

Gaikwad *et al*. [43] performed cryogenic treatment on both workpiece and Copper electrode. Cryogenic treatment was performed at -185℃. It was found that both MRR and TWR increased with the increase in current. The cryogenically treated NiTi workpiece and non-treated Copper provided more MRR. With higher current values TWR rate was also more. TWR was less in case of cryogenically treated copper and cryogenically treated NiTi. It was found that tool wear rate in case of treated copper and treated NiTi with pulse on time was more. With the increase in pulse off time, MRR and TWR started declining. Both MRR and TWR were more in case of treated NiTi and non-treated copper. The optimum process parameters for the machining of cryogenically treated NiTi alloy with cryogenically treated Copper electrode were gap current 16 A, pulse on time 38µs, pulse off time 5µs and optimized MRR at these settings was 7.08mm^3/min [44].

II. CONCLUSION

There are myriads of electrical and thermally conductive materials that can be used as a tool in EDM. Primary research in the field of EDM is focused on minimizing the tool wear and surface roughness along with maximizing the MRR. Tool wear is inevitable in the case of EDM, but new materials and new methods of preparation of tool electrode can help to reduce the wear rate to a significant level. Tools made by the powder metallurgy process possess high hardness and good bonding between the particles of the tool, which increases the shape retention capability of the tool and reduces the tool wear. Cryogenic treatment of the EDM electrode helps in the refining of the grains. It fills the voids in the crystalline structure, thus improving the electrical and thermal conductivity of the EDM tool. Cryogenically treated powder metallurgy electrode has given good results in reducing the tool wear, as found from the literature. Commonly machined materials with EDM are die steels and alloys; there is less research carried conductive ceramics and on composites, which can be a good substitute for various components in the future. Biodegradable materials which can be used in medical implants can be easily machined, and their surface can be easily modified to suit the human body environment using the electric discharge machining

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