Experimental investigation and optimization of Electric Discharge Machining Parameters for surface modification of AZ31 (Magnesium alloy) for biomedical applications

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CERTIFICATE

I hereby certify that the work being presented in the dissertation entitled "Experimental investigation and optimization of Electric Discharge Machining parameters for surface modification of AZ31 (magnesium alloy) for biomedical applications" in partial fulfillment of the requirement of the award of the Degree of master of technology and submitted to the Department of Mechanical Engineering of Lovely Professional University, Phagwara, is an authentic record of my own work carried out under the supervision of Mr. Karanvir Singh (Asst. Professor) Department of Mechanical Engineering, Lovely Professional University. The matter embodied in this dissertation has not been submitted in part or full to any other University or Institute for the award of any degree.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABBREVIATIONS AND SYMBOL USED

Abbreviation	Explanation
AC	Alternate Current
AISI	American Iron and Steel Institute
ASTM	American Society for Testing and Materials
CNC	Computer Numerical Control
DCT	Deep Cryogenic Treatment
EDM	Electric Discharge Machining
MRR	Material Removal Rate
PM	Powder Metallurgy
RWR	Relative Wear Rate
TWR	Tool Wear Rate
XRD	X-ray Diffraction

Symbol	Meaning
Al	Aluminum
Cu	Copper
Cr	Chromium
Ti	Titanium
TiC	Titanium Carbide
W	Tungsten

ABSTRACT

Unconventional machining processes have become very popular during the recent years for machining hard and brittle materials. EDM is one of the unconventional machining processes which utilize thermal and electrical energy to turn a rigid, brittle component into a complex shape. EDM is commonly used in the die making industry, drilling industry and also used to craft complex and intricate shapes on materials. EDM's capability in precise fit machining has found its application in the medical field also. Biomedical implants which require greater accuracy and precision are being machined with EDM process. AZ31 is a magnesium alloy which can be used in these implants which provide structural stability to the bone. So, this experimental study will be focused on finding the optimized process parameters for the machining of AZ31 with an electrode made up of pure Titanium and to analyze the machined surface for surface finish and corrosion resistance.

CHAPTER -1 INTRODUCTION

EDM stands for the Electric Discharge machining process. It is a thermoelectric process which is a type of nonconventional machining processes. These processes are called as nonconventional because these processes do not use conventional tools(turning tool, shaper tool, milling tools, form tools) directly but as a substitute use the energy in direct form, for example, energy can be mechanical, chemical, electrochemical or thermoelectric. EDM is very useful in precision machining, die cavity and producing obscure 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 first revealed that electric sparks cause erosion. In the 20th century year 1943 two Soviet scientist Dr. B.R Lazarenko and Dr. N.I. Lazarenko discovered that the spark erosion can be controlled if the electrodes are submerged in a dielectric liquid. This discovery leads to the formation of first spark erosion or EDM machines. From their invention in 1943 to CNC EDM a lot has changed in the region of EDM. But 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 process. The main challenges in EDM process are tool electrode wear, low material removal rate , large operation time, surface amendment and surface roughness.

Biomedical implants nowadays are center of research in medical sciences. Biomedical implants are necessary to be inserted when there is a fractured bone or tissue. Most of the times implants inserted are permanent implants means they will need another operation to remove the implant and they could react with body. Temporary or biodegradable implants do not require extra surgery to remove them from system they slowly degrade out of the system and are non-toxic. Magnesium alloys fall in the category of degradable material. Magnesium is biocompatible and it provides necessary physical strength for the tissue to grow up and in the time being it get dissolved by the body environment. The structures of these 3-D implants are very complex and require precision in their machining with maintaining their structural stability. Electric discharge machining is recognized for precision machining and it does not apply any force on the workpiece. Thus the abilities of EDM process can be utilized in medical field.

1.2. THEORY OF EDM-

As stated earlier EDM is a thermal erosion process. The job or the workpiece needs to be conductive in order 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 identical to the final workpiece. Die-sink EDM is a variant of EDM process, other include wire cut EDM.

CONSTITUENTS OF EDM-

1.2.1. Work piece-It is the material to be machined. Workpiece needs to be electrically conductive in order to be processed at EDM. It is generally made anode.

1.2.2. Tool Electrode- Tool electrode or simply tool is made up of a material which has high electrical and thermal conductivity as well as high hardness and melting point. It is generally made cathode(-).

1.2.3 Servo system- 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.

1.2.4 Dielectric medium- the Dielectric medium is necessary for the 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. Here are some of the uses of dielectric fluids-

- Helps in creations of plasma channel by ionizing.
- Provide the flushing effect means to take away the material removed from the workpiece.
- Also helps in heat transfer, provide a cooling effect to both electrodes.

1.2.5 Power Source-This unit convert the AC current from the core power supply into a pulsed direct current which is used for the generation of spark.

1.2.6 Pulse Generator-provide pulsating voltages and current for a definite expanse of time.

1.3. WORKING OF EDM

In Die-sink EDM the material which is going to be machined is placed inside the dielectric liquid. The tool is made cathode (-).And workpiece is made as anode. No contact between the two electrodes is permitted. As the voltage between the two electrodes is applied, the cathode is made is 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 as ionization of the dielectric. This ionization results in the formation of a plasma channel amid the electrodes. The electrons and ions strike 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 the material removal. Temperature produced by this energy lies in a range from 8000℃ -12000℃.The material which has been removed from the workpiece by melting and vaporization is flushed away by the circulating dielectric fluid. In EDM the material removal rates are very low.

Again the same cycle starts with 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 wild spark discharge. This may result in decreasing the MRR and uncontrolled discharges lead to poor surface quality, more wear of the tool electrode. After the pulse is off the fresh dielectric from the surrounding area replaces the ionized particles of the dielectric. This helps in stabilizing the spark. Only sparking is desired in EDM rather than arcing. Arcing leads to localized material removal at a particular point whereas sparks

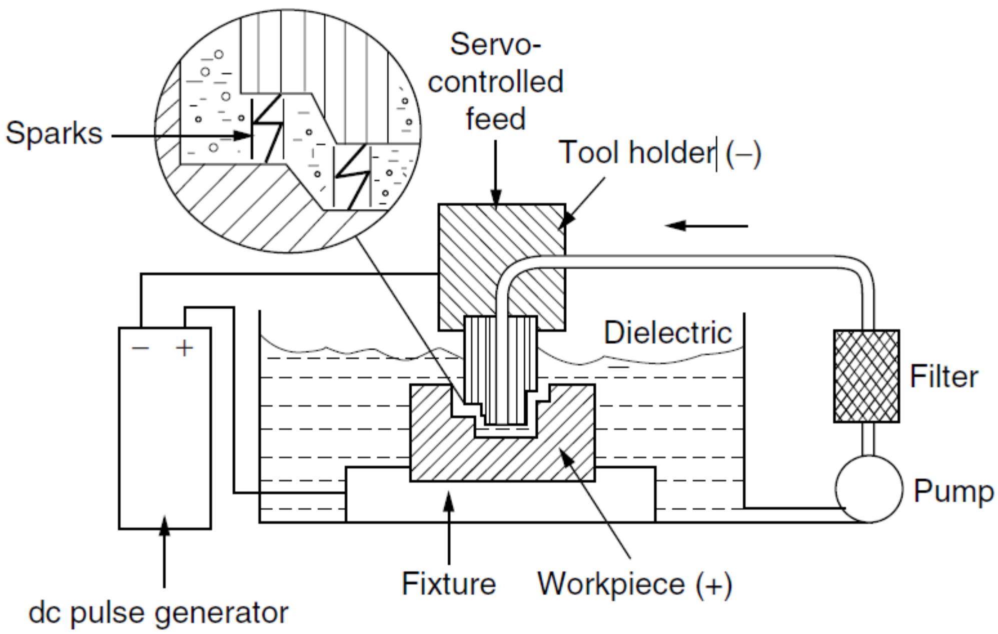

Figure 1.3- Components of EDM process [1].

get distributed all over the tool surface leading to uniformly distributed material removal under the tool.

1. 4. PROCESS PARAMETERS OF EDM

The performance of the EDM can be controlled by optimizing the process parameter. Process parameters are factors or properties by varying these we can achieve optimum values of MRR,TWR and surface finish. Process parameters in EDM can be categorized into two types-

- Electrical parameters
- Non-electrical parameter

4.1 Electrical Parameters-

I. Polarity-It is the assignment of the negative or positive electrode to either tool or workpiece. Mostly straight polarity is preferred for operation i.e. tool is assigned cathode and workpiece anode.

II. Peak current-It is the maximum value of current presented by each pulse from the power source. During discharge, this is the maximum value of current.

III. Pulse on time-It is the time during which machining is performed. It is measured in microseconds. For longer pulse on durations more will be the material removal rate.

IV. Pulse off time- It is the time between successive sparks. It is also measured in microseconds. Pulse off time is essential for flushing the eroded material debris. There is no spark during pulse off time. If the pulse of time increases then it will increase the machine time, but there will be sufficient time for flushing any derbies.

V. Gap voltage-It is the voltage measured between the two electrodes before the generation of the spark.

VI. Average current-It is the mean taken of the maximum and minimum values of the peak current in the spark gap.

4.2 Non-Electrical Parameters-

I. Electrode material-Tool in EDM should have high electrical and thermal conductivity, Its shape should be same as the final shape of the job. Electrode composition also affects the EDM process, a composite electrode can utilize the benefits of two or more metals.

II. Dielectric fluid-Dielectric fluid should have high insulating properties until required gap and voltage is achieved. It flushes the debris and lowers the temperature of workpiece and tool. Different dielectric fluids have different properties which can be utilized in different working conditions.

III. Powder mixed-Sometimes a powder is mixed with the dielectric fluid generally silicon powder or aluminum which helps in the generation of plasma channel and stabilize it achieving more MRR and better surface finish.

1.5. PERFORMANCE PARAMETERS

Performance parameters give or measure the results of EDM , by variation in the input or process parameters. Main performance parameters are-

I. Material Removal Rate or MRR- It can be defined as the rate at which material is eroded from the workpiece. It signifies the volume of material removed. It is measured in mm^3/min. High material removal rates are preferable to reduce the machining time.

II. Tool Wear Rate or TWR –Due to spark erosion tool electrode also face some wear. It is the rate at which material is removed from tool electrode per unit time. This parameter is of major concern. As the increase in tool wear leads to decrease in tool life.

III. Surface Roughness- It is related to the final surface finish achieved after the machining process. It is measured by deviation of the actual surface from the ideal surface. If these eccentricities are large then the surface is rough. Our goal is to achieve minimum surface roughness as possible.

IV. Recast layer thickness-Recast layer is the hardened molten metal which is eroded from the workpiece. It is the uppermost layer of the workpiece.

V. Wear Ratio or Relative wear rate-It is the ratio of the TWR/MRR. This ratio is also called as relative tool wear rate. Lowest TWR/MRR ratio gives the ideal tool-workpiece combination and optimized process parameters.

1.6. TOOL MATERIAL

There are various types of tool electrodes available which can be used in EDM process. As tool material need to be electrically as well as thermally conductive, it should also possess corrosion resistant property so that the tool suffers less wear from the spark which is our major objective. So a material with high conductivity, high melting point and hardness are used. Below some materials are given which are being used in industry-

I. Copper- This is the extensively used electrode for machining in EDM. Copper has high conductivity and it is inexpensive and it gives the good surface finish. But copper is difficult to machine as compared to other electrodes.

II. Brass-A alloy made from the grouping of copper and zinc. It can be given any complex shape easily means easy to machine. This material is generally used in EDM wire cutting as an electrode. Wear resistance of brass is very less as compared to copper electrodes.

III. Copper Tungsten electrodes –This type of electrodes are manufactured by powder metallurgy process, combining the properties of both the materials. The high conductivity of copper and high hardness and melting point from tungsten. It provides less wear of the electrode and good surface finish. However, the manufacturing process is expensive if compared with the other electrodes.

IV. Graphite –It is also widely used in industry. Electrodes of graphite can be easily machined and they provide the good surface finish. As compared with copper its density is 5 times less than the copper, thus graphite electrodes are lighter in weight also gives more MRR and less wear.

V. Silver tungsten- It is a composite of silver and tungsten. In the matrix of silver, tungsten carbide particles are dispersed. Silver has high electrical conductivity and tungsten offers high erosion resistance. But the cost of these electrodes is high.

VI. Molybdenum- This material is used in wire EDM. This material has good conductivity as well as good tensile strength. It is used in applications where small diameter wires are needed for slot work.

VII. Tellurium copper- It is used in applications where fine finishing is required. Its machinability resembles brass, but less than copper.

1.7. CHALLENGES IN EDM PROCESS

EDM process has proven beneficial for the cutting of hard materials and it can be easily automated but like any other process EDM too has some shortcomings. However, some of these can be controlled up to certain limits with the optimization of the process parameters and some of them are inherent to the process. Here are a few of them-

I. Low MRR-EDM has low material removal rates because the whole volume of the cavity is to be removed by the melting and the vaporization of the workpiece. Also, removal occurs in the pulse on time only which leads to longer machine time.

II. Tool Wear –As in conventional machining, there is tool wear as the tool is used to perform machining. Similarly, in EDM tool wear occur. Positive ions from the plasma channel and workpiece impinge on the tool surface leading to the tool wear. High temperature and melting also contribute to the tool wear.

III. Surface roughness-Spark generated between the two electrodes removes material in form of craters on the surface of the workpiece. The spark will be generated at the point where the gap between the workpiece and tool is minimum. Spark does not take place side by side they occur randomly it is generally assumed that spark take place side by side. Because of the craters the surface roughness of the finished surface may increase or decrease depending on the input parameters.

IV. Overcut and Taper cut-Overcut is the gap between the tool surface and the machined surface. As earlier stated, machining occurs between the nearest point of tool and workpiece, the side surface of the workpiece may get machined. Taper cut is the distance between the side surface of the tool and the machined surface. Taper cut can be avoided by insulating the side of the tool. Overcut and taper cut in excess can result in poor dimensional accuracy. Overcut is inherent to the EDM.

CHAPTER 2 : LITERATURE REVIEW

This review is about findings of various researchers about electric discharge machining, use of various electrodes in EDM, and the cryogenic treatment of the EDM electrodes and the workpieces and the effect of these changes on MRR, tool wear, and surface roughness.

I. Various Electrodes used in EDM

M.P. Samuel et al.,(1997)

Their work is on powder metallurgy electrodes for electric discharge machining. They used electrolytic copper powder 99.7% pure for the making of tool and workpiece material was hardened steel. They studied the effect of the pulse current, pulse frequency, and compact pressure. Increasing the compact pressure from 62 to 625Mpa increases 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. High frequency with the high current results in high MRR. Low compacting pressure and low sintering temperature result in higher tool wear in EDM [2].

Li Li et al.,(2001)

They also studied the powder metallurgy electrodes for EDM machining. The composition of the tool was Copper 25%-Tungsten 75% (with Nickle 3.5% and varying proportions of the Titanium carbide). Workpiece material was hardened steel. Main process parameter was the composition of titanium carbide. TiC increases the solubility of copper in tungsten. Relative density increases first and then decreases as composition varies from 5 to 50%.Tool wear first decreased and then increased. MRR increases first and then decreases. Proper densification is achieved at 15 % of TiC in the electrode. MRR was high at 15% of TiC similarly, tool wear was also low at 15% of TiC in the electrode. Electrical resistivity is also low at this value [3].

B.H. Yan et al.,(2002)

Copper chromium composites were used as tool electrodes. Response characteristics were studied on the surface of AISI 1045 medium carbon steel with peak current, polarity, pulse on time, open circuit voltage and duty factor as process parameters. Kerosene was used as the dielectric fluid. 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. Material removal rate was high when tool electrodes made at pressure 20 MPa and 30 MPa were used because at a lower pressure the copper and chromium particles get detached from the electrode which results in unbalanced discharge. 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. Negative polarity also gave more surface roughness than positive because when the electrode was made anode Cu-Cr material adhere to the surface of the workpiece and making its surface rough [4].

I. Puertas et al.,(2004)

Their work involved the machining of the conductive ceramics. Three ceramic materials which included Boron carbide, Silicon carbide, and Tungsten carbide were used as workpieces. Electrolytic Copper was used for machining these workpieces with peak current, pulse on time and duty factor as process parameters and material removal rate, surface roughness and tool wear rate as response factors. It was found that surface roughness increases with increase in current intensity in case of silicon carbide and tungsten carbide but decreases in case of boron carbide. Surface roughness increases with increase in pulse on time and increasing duty factor worsen the surface of silicon carbide but effects were opposite for boron carbide.

Electrode wear increases with increase in peak current in case of boron carbide but effects were not same for the other two workpieces. With the increase in pulse on time tool wear rate decreases in case of boron carbide while for the other two results were opposite. With longer duty cycles the tool wear rate was increased in case of boron carbide and silicon carbide but in case of tungsten carbide, it decreases after reaching a maximum value.

Material removal rate was increased with increase in peak current as well as with duty cycle. With increasing the pulse on time material removal rate was decreased in case of silicon carbide and tungsten carbide [5].

Shankar Singh et al.,(2004)

Their work was a comparison study among responses received from various types of electric discharge machining electrodes. Electrode materials were Copper, Copper Tungsten, Brass, and Aluminum. Machining was performed on EN-31 steel with discharge current, reverse polarity and gap voltage as process parameters. Results showed that with an increase in discharge current material removal rate was increased. It was found that Copper and Aluminum electrode offered highest material removal rate trailed by Copper Tungsten and Brass. Copper electrode showed a constant diametrical overcut with the intensification of the discharge current. Aluminum 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. At higher discharge current Copper and Aluminum gave rough surfaces as compared to lower current values. Brass also provided a good surface with a small increase in roughness as current increases after Copper. It was concluded that Copper and Aluminum provide better results with an increase in discharge current [6].

S.K. Ho et al.,(2007)

Surface modification using powder metallurgy electrodes was studied by the authors. Powder metallurgy Copper electrodes were prepared at compaction pressures of 15 MPa, 32MPa, and 300 MPa. Solid Copper electrode was also used for comparative study. Workpiece material was Titanium alloy Ti–6Al–4V. Process parameters were polarity, tool electrode and peak current, open circuit voltage, pulse on/off time were fixed parameters. It was found that more thick recast layers were obtained using the straight polarity where thickness range was from 4-11 µm. Negative polarity caused uniform distribution of recast layer. Using solid Copper electrode with negative polarity increases the hardness of the recast layer up to 3 times than with straight polarity with powder metallurgy electrodes. Reverse polarity was found suitable for surface alloying because using a tool with positive polarity to machine a workpiece with low thermal conductivity was easy because the heat energy of the discharge performed mainly on the tool electrode. This reason united with the weaker bonding of atoms of powder metallurgy electrode provided more alloying. Positive polarity resulted in higher surface roughness. Surface roughness was also affected by compaction pressure. Low compaction pressure resulted in high resistivity which gave rise to uneven sparking thus creating a rough surface. The powder metallurgy electrodes gave more alloying than the solid electrode. Electrodes prepared at 32 MPa provided better alloying characteristics than other [7].

Naveen Beri et al.,(2008)

Tool electrode was made through powder metallurgy process. This was a comparison study between powder metallurgy tool electrode and the conventional electrode. The composition of the tool was Copper 30% and Tungsten 70% made by powder metallurgy and another electrode was simple copper. Workpiece material was AISI D2 steel. Taguchi method was used to find the optimum level of the process parameters. Process parameters were electrode material, current, duty cycle and flushing cycle. Copper electrode is useful in attaining maximum material removal rate. Copper -Tungsten electrode gave minimum surface roughness. Best parameters for Cu electrode were 10.5-ampere current, 0.66 duty cycle, and 0.7kg/cm^2 flushing pressure for material removal rate. 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 [8].

D. Kanagarajan et al.,(2008)

Their work involved the machining of a Tungsten Carbide –Cobalt workpiece which was made by powder metallurgy process. Cobalt percentage was 30% and Tungsten Carbide was 70%. The tool was made up of pure Copper in the shape of the cylindrical rod. Process parameters consisted of electrode rotation, pulse on time, peak current, flushing pressure and response factors were surface roughness and material removal rate. 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 peak current, high rotational speed, high flushing pressure resulted in increasing the material removal rate and decreasing the surface roughness. The error between anticipated outcomes and the practical value was 5 percent. Material removal rate was found directly proportional to the quantity of cobalt because cobalt has higher thermal conductivity as compared to tungsten and it was easily removed. It was also determined that with higher flushing pressure and rotational speed surface finish can be increased [9].

L.C. Pathak et al.,(2009)

A new composite material was made and tested in this research. Zirconium diboride ($ZrB_{2)}$ and Copper (Cu) was used to make the composite tool for electric discharge machining with varying percentage of Copper in the new tool. Mild steel was used as a workpiece. Peak current, pulse on time, gap voltage, and duty factor were the fixed process parameters. Copper powder was mixed in various compositions with ZrB_2 powder. Pallets of size 6.6 mm diameter and 5 mm thickness were made at compaction pressure 250MPa and sintering temperature of 1250°C. 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. Material removal rate 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 case of the composite tool than the Copper tool because of higher material removal rate [10].

P.K. Patowari et al.,(2011)

Their work involved the use of powder metallurgy electrode for studying the recast layer characteristics after machining. Recast layer is the solidified molten metal from workpiece and tool that settles on the top layer of the workpiece after machining. Tool electrode was made from Copper and Tungsten and workpiece material was C-40 steel. Various process parameters were compaction pressure, sintering temperature, electrode composition, pulse on time, peak current and polarity. Tungsten and copper powder of 325 mesh was used. Tungsten copper compacts were made at different compaction and sintering temperature. Best results were obtained at composition 75%-25% of Tungsten-Copper. The recast layer was having a variable thickness of 3-785 micrometers. In the layer, there was the presence of Copper, Tungsten and Tungsten carbide. 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, peak current 8-ampere, pulse on time 48 microseconds, and straight polarity [11].

Naveen Beri et al.,(2011)

They have worked on the optimization of the EDM process with Cu-W electrode made with powder metallurgy using grey relation theory. Workpiece material was AISI D2 steel in kerosene as a dielectric with Cu-W (25% Cu and 75% W) PM electrode. Process parameters were electrode material, duty cycle, flushing pressure and current. Optimization of complicated multiple performance characteristics can be greatly simplified by using grey relation theory. It is shown that during machining of AISI D2 steel performance characteristics of the EDM process are improved by using copper tungsten electrodes made through PM and the duty cycle parameter has the strongest effect on the multiple-performance characteristics. The optimum machining parameters as suggested by this study were with copper tungsten electrodes made through PM, 10.5 A current, 0.66 duty cycle and0.3 Kg/cm2 flushing pressure. The study also revealed that copper tungsten PM electrode gave better multi-objective performance than conventional copper electrode [12].

M.B. Nadilman et al.,(2011)

They fabricated an electric discharge machining tool using powder metallurgy techniques. Two different compositions of Copper and Tantalum Carbide were employed to get the well-suited characteristics of EDM tool. Process parameters for the operation were powder composition, compaction pressure, sintering temperature and time. Copper powder 99% pure of 200 mesh and TaC 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. With the increase in TaC composition electrical conductivity of the electrode was decreasing .Cracks were detected on the surfaces of the electrodes which were sintered at 850°C for 50 minutes and their resistivity also increased. The thermal conductivity of the green compact electrodes was little high than the sintered ones. The density of the sintered electrodes was less than the compact electrodes. Under sintering condition, the electrodes cannot be used because of the low conductivity [13].

Harpreet Singh et al.,(2012)

Their study was focused on the effect of the pulse on time and pulse off time on machining of AISI D3 die 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 MRR [14].

Mahani Yusoff et al.,(2013)

They study the effect of sintering parameters on the microstructure and properties of the copper-tungsten carbide composites. The composites were composed of Elemental copper 99.8% pure having average particle size 22.3 µm, tungsten 99.9% pure, average particle size 11.4 µm and graphite powders 99.8% pure, average particle size 17.0 µm. The process parameters were sintering temperature 800 to1000℃, compaction pressure 300 MPa. High holding time was used to eliminate impurities. Density was increased from temperature 800℃ to 950℃. And after 950 it started decreasing. Hardness increased till 950℃ and after a further increase in sintering temperature lead to decrease in hardness because of the grain growth of Copper started. Electric conductivity was also increased with increase in sintering temperature from 800℃ to 950℃.This was due to the elimination of the pores at high temperature [15].

F.klocke et al.,(2013)

Their work was focused on the analysis of material removal and tool wear with the help of graphite electrodes. Tool material were five different graphite electrodes each having a different grain size. Process parameters were Discharge current, pulse duration and pulse interval time. Graphite electrodes integrate some of the oil volumes into themselves due to their porous nature. MRR was increased with the intensification of the pulse current. With the increase in pulse duration, MRR was declined. Negative tool wear also occurred which means that material from workpiece got deposited on the tool. This was maybe because of poor flushing conditions. There was no simple dependency of MRR on the grain size [16].

B. Mohan et al.,(2014)

The main focus of their study was on the effects of tool electrode resolidification on the surface hardness. The tools selected for the process were Tungsten carbide and Brass with AISI 202 stainless steel as the workpiece. Gap voltage, peak current, and pulse on time were fixed parameters while electrode material and polarity were varying parameters.

The results revealed that the higher the melting point of the tool electrode high will be the thickness of recast layer. Thus workpiece machined with tungsten carbide has higher surface hardness, than the original because of the high hardness of Tungsten carbide 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. Positive polarity region 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 [17].

Rajneesh Kumar et a.,(2014)

They studied the effect of EDM process parameters on the tool wear. Tool material was copper and workpiece material was mild steel. Input parameters were discharge current, pulse on time and gap voltage. Output parameters were tool wear rate and relative tool wear rate. 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. This phenomenon resulted in increased MRR and decreased tool wear rate. Relative wear rate was increased with the pulse on time and with an increase in current TWR was also increased. Increase in gap voltage leads to decrease in the tool wear rate [18].

Tijo D. et al.,(2014)

Their research work involved the surface modification of the Aluminum using electric discharge machining. Tool electrode used was a green compact electrode of Copper –Tungsten with equal proportions made by powder metallurgy process. Process parameters were reverse polarity, peak current, pulse on time and compaction pressure. Gap voltage and duty factor were fixed parameters. During machining, the tool gets worn out. Tungsten from the tool formed Tungsten Carbide by reacting with the carbon from the dielectric fluid. This Tungsten Carbide gets deposited on the workpiece surface along with the copper. Lower compaction pressure, higher peak current, and pulse on time backed both deposition rate and Tool wear rate. But when the pulse on time was increased from 200µs to 300µs then tool wear rate and deposition rate both decreased. The reason was that the energy density on the discharge spot get decreased and heat did not contribute to the material removal rate [19].

Vijay Kumar et al.,(2014)

Their study comprised of a selection of the best process parameters for the machining of H-13 tool steel. The tool electrode was a U- shaped copper electrode equipped with a channel for internal flushing. Process parameters were electrode thickness, pulse on time and discharge current. Output parameter was overcut. Overcut is the difference by which the machined hole in the workpiece surpasses the electrode size .Cavities produced during machining are always larger than the electrode size. The difference between the size of the cavity and the electrode is called overcut. It was found that most significant factor affecting the overcut was electrode thickness.

As the thickness of the electrode increased the sparking area also increased which increased the overcut. Overcut was decreased slightly with an increase in pulse on time. Increase in discharge current from 1-ampere to 3-ampere first increased the overcut but then it was decreased slightly when discharge current was increased from 3-ampere to 5-ampere [20].

Nibu Mathew et al.,(2014)

Their study involved the tool wear rate of two different electrodes used in powder metallurgy process. One electrode was Copper tungsten electrode in proportions of 75-25 percent respectively made by powder metallurgy and other was a solid Copper electrode. Process parameters were the pulse on time, peak current, and duty cycle with negative polarity. Machining was performed on an H-11 Chromium hot work steel. It was found that for PM electrode the tool wear rate was decreasing continuously with increase in peak 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. With the increase in duty cycle, TWR for conventional electrode decreased. PM electrode showed better tool wear rate than the conventional electrode. TWR increased with increase in duty cycle, gap voltage and peak current. Optimized parameters for minimum tool wear rate in case of PM electrode were 4-ampere peak current, 40 volts gap voltage, and 0.72 duty cycle [21].

Priyaranjan Sharma et al.,(2014)

They used tubular Copper and Brass as tool electrode with a hole in the center. The workpiece was AISI 329 stainless steel also called duplex steel. Process parameters were peak current, pulse on time, pulse off time and flushing pressure. Distilled water as dielectric was used through the flushing holes in the electrodes. It was observed that MRR and TWR both increased with increase in peak current. Higher peak current gives rise to higher energy density which results in higher temperatures. TWR in case of the Brass electrode was more because of the low thermal conductivity of the Brass electrode. Taguchi and Grey relation theory was used to identify the best selection 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 [22].

Amoljit Singh Gill et al.,(2015)

In their study, they have used electrical discharge alloying (EDA) to modify the surface of high carbon steel En31 with the help of tool electrode (Copper-Chromium-Nickel) manufactured by the powder metallurgy (PM) process. They designed the experiment using Taguchi method and the L18 orthogonal array was used to find the best level of process parameters. The process parameters were tool polarity, the percentage of alloying element in the tool, peak current, pulse on-time, duty factor, and voltage. There was an increase in the microhardness of the workpiece by the amount of 139.7%. XRD analysis of the surface showed a significant material transfer (Chromium, nickel, and copper) from the tool electrode to the machined surface in the form of chromium carbide (Cr_3C_2). There was an increase in carbon content due to deposition of carbon which was produced due to dielectric breakdown. Best micro-hardness results were obtained by the positive tool polarity, a tool with 15 % W, 15A peak current, 200µs pulse on-time, 64% duty factor and 50V discharge voltage[23].

M.A. Moudood et al.,(2015)

The main process parameter selected by them was material removal rate. The tool was a square-shaped copper electrode. The workpiece material was Al_2O_3 ceramic with the assisted electrode. AE is a method which helps in machining the non-conductive components. In the method, the workpiece is coated with a metal foil to initiate the spark. In the present case, the copper foil was applied over the surface of the workpiece. Process parameters were gap voltage and pulse on time. 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, peak current 1.1 A, pulse on and off time at 8µs. Beyond the range of gap voltage (12-14 V), the material cannot be machined because past this range conductive carbon layer cannot be formed. When the pulse on time increased from 6 to 8µs at constant 14 V and peak current 1.1A MRR increased about 20% from the previous value. Results also showed that the workpiece cannot be machined with a copper tool having straight polarity [24].

P.K. Patowari et al.,(2015)

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%). The particle size of the powders was 325 mesh. Process parameters were pulse on time, pulse off time, peak current, polarity, and compaction pressure. Electrodes were prepared under 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 recast layer was formed on the surface tool which contained particles of WC, Cu, and Fe. This recast layer improved the hardness of the workpiece. At lower values of peak current and pulse on time the recast layer was smooth and thin but at high peak 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 [25].

Can Cogun et al.,(2015)

They also studied the effects of powder metallurgy electrode on the surface characteristics of the workpiece with different tools. Tool electrode was made by using Cu and B_4C powder with proportions 80%-20% respectively, a pure Cu electrode made by powder metallurgy and a solid electrolytic Copper electrode. Workpiece material was SAE 1040 steel with process parameters electrode material, pulse on time and discharge current and positive polarity. 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 workpiece [26].

Ryota Toshimitsu et al.,(2016)

Their motive was also to study the surface characteristics of the ED machined workpiece. The workpiece material was tool steel SKD11 and the tool electrode was solid Cu electrode. The dielectric medium was kerosene with Chromium powder mixed in it. Process parameters were discharge current and powder concentration (1-5g/L). 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 a decrease in discharge current. High concentration of Chromium leads to increase in surface roughness as well as in hardness of the workpiece[27].

Himanshu Payal et al.,(2016)

Main response parameters of their study were MRR and TWR. They used two different electrode one was solid Cu, graphite electrode and Cu(20%)-W(80%) electrode made by powder metallurgy process. Workpiece material was H11 hot die steel. Pulse on time was the only varying parameter with level settings at 10, 20, 30, and 40µs with straight polarity. 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 electrode followed by Cu electrode and then Cu-W electrode. Tool wear rate get decreased with increase in pulse on time because longer pulse duration helped in heat dissipation from tool to workpiece. Graphite tool gave maximum TWR followed by Cu and least TWR was provided by Cu-W [28].

J. Jeykrishnan et al.,(2016)

They used a Copper electrode covered with nickel as the tool electrode. Inconel 825 alloy was used as workpiece and kerosene as the dielectric medium. Process parameters were discharge current, pulse on time, and pulse off time. Main response parameter selected was surface roughness. It was found that the most significant factor which affected the surface roughness was discharge current. Increase in current at shorter pulse duration resulted in regular sparks which contributed to smooth material removal rate 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. Higher pulse off time provides enough time for the dielectric medium to remove the molten material between the tool and the workpiece [29].

Parveen Goyala et al.,(2017)

The objective of this study was to analyze the surface properties of a workpiece after machining it with the electrode made by powder metallurgy process. Tool electrode was made from Copper and Manganese powder. Two different proportions of powder Cu(80%)-Mn(20%), Cu(70%)-Mn(30%) were used. The solid Copper tool was also used to know its effect on the surface properties of the En-31 die steel which was the workpiece material. Process parameters were electrodes, discharge current, pulse on time and pulse off time. Manganese was used because it enhances the machinability, strength, and hardenability of the steel.

Electrode with composition 70-30 of Cu-Mn provided the maximum microhardness as compared to the electrode with 80-20 of Cu-Mn composition and to the solid Copper electrode. As the peak 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 peak current and pulse on time [30].

Shoaib Sarfraz at al.,(2017)

Their study included the two different types of dielectric in machining and to study their effects on the MRR and tool wear rate. Aluminum 6061 was used as the workpiece and a Cu electrode was used for the machining. 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 at a lower temperature. The surface of a workpiece machined with kerosene was smoother than one machined with water. So kerosene was preferable over water [31].

II. Cryogenic treatment in EDM

This section contains the use of the Cryogenic treatment in electric discharge machining. Cryogenics is the science of dealing with an extremely low temperature between -150℃ to -273.15℃ which is absolute zero. Cooling the materials to low temperature helps in increasing the mechanical and electrical properties of the materials. Tools, as well as workpiece both, were treated cryogenically by the researcher to find the appropriate results.

Murali Meenakshi et al.,(2009)

They used both cold treated and cryogenically treated Copper electrodes. Beryllium Copper alloy was used as the workpiece material. The process parameters were the pulse on time, pulse off time, duty factor and discharge current. The compact structure of copper obtained after DCT reduced the electrical resistivity of the Copper electrode which was cold treated 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 [32].

Suleiman Abdulkareem et al.,(2009)

Main response parameter of their experiment was the electrode wear rate. They used the liquid Nitrogen during the experiments to utilize its cryogenic properties. Tool material was Copper and the workpiece was a Titanium alloy Ti-6Al-4V. Process parameters were discharge current, pulse on time, pulse off time, and gap voltage. 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 bulging effect on surface roughness. Nitrogen cooling caused a reduction in vaporizing and melting of the electrode which results in smoother surfaces [33].

Rupinder Singh et al.,(2011)

The objective of their study was to find the effect of cryogenically treated tool electrodes on the various response characteristics. Titanium, Copper, and Copper Chromium were selected as the tool materials. Two different sets of tool electrodes were prepared in which one set contained the cryogenically treated electrodes and the other had non-treated electrodes. The workpiece material was a Titanium alloy named Titan 15 ASTM grade 2. Workpiece material was also treated with the liquid nitrogen. Process parameters were peak current, workpiece and tool material. Response parameters were MRR, TWR, surface roughness, and dimensional accuracy. Cryogenic treatment was done at -80℃. L9 orthogonal array was used to optimize the process parameters. 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. MRR and TWR rate showed 60.39% and 58.77% improvement respectively [34].

Y. Yildiz et al.,(2011)

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. It was found that in Cu alloys cryogenic treatment produces a homogenous structure with dissolving gaps and dislocations which in turns increase the conductivity. 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 [35].

CHAPTER 3: SCOPE OF THE STUDY

Electric discharge machining is an unconventional process which is used to machine materials which are electrically conductive and hard to shape. The main issues which occur during EDM are electrode tool wear, poor surface finish and slower material removal rate. To improve these output parameters, materials which possess high corrosion resistance should be used.

A biomedical implant is a device built to support or to replace an organic structure. The shapes of such implants are very complex and require intricate details which are difficult to impart using conventional machining process. Electric discharge machining has emerged as a decent technique for manufacturing of the biomedical implants. Currently, the research is focused on the biodegradable implants. These implants once implanted in the body need not be removed with a second surgery because they get dissolved in the body. Our work will be focused on-

- Improving the surface finish of the workpiece for medical implants.
- To find the best set of the process parameter to machine the workpiece efficiently and accurately.

CHAPTER 4- OBJECTIVES OF THE STUDY

Objectives of this study are-

- To find the optimized process parameters for the machining of AZ31 Magnesium alloy using the Titanium electrode.
- To minimize the surface roughness of the AZ31 Magnesium alloy and to minimize the tool wear rate of the electrode
- .To successfully implements Electric Discharge Coating of the workpiece with Titanium.
- To study the microstructure and recast layer of the machined workpiece.

CHAPTER 5: EQUIPMENT, EXPERIMENTAL SETUP, AND MATERIALS

EDM tool electrode will be made up of pure Titanium. Titanium has high strength and high corrosion resistance which makes it less vulnerable to the wear which will occur during the spark erosion process. Other reasons are that it is already being used in the dental, bone and knee implants and it is nontoxic to humans if we consider its interaction with the bodily fluids of humans.

Workpiece material is AZ31, a magnesium alloy. The composition of the alloy is Magnesium 97%, Aluminum 2.50- 3.50 %, Zinc 0.60-1.40%, Manganese 0.20% and Copper 0.050%. AZ31 possess good machinability and the dust produced during machining is combustible thus its machining require extra attention. Die sink EDM can be a good alternative for machining this alloy because in die sink EDM workpiece is submerged in the dielectric fluid. Magnesium alloys possess huge applications in the field of medical implants. Magnesium is compatible with our body and it can dissolve in our body's biological atmosphere in spite of this it remains harmless. Magnesium alloys can be used in vascular stents and bone repairs. Medical implants require intricate shapes with high tolerance and these can be easily machined with EDM and reactivity of Magnesium makes it degradation rate very fast and to reduce this rate a coating of a material which has high corrosion resistance and non-toxic toward humans must be used. Coating using electrical discharge machining is very effective method to coat materials with high melting points and strength.

The Experiments will be performed on a die sinker EDM machine. Other equipment required are Scanning Electron Microscope for the surface imagining of the workpiece and the tool, surface roughness tester for measuring the surface roughness of the workpiece and tool before and after machining.

CHAPTER 6: RESEARCH METHODOLOGY

Optimization is a process of finding the best set of parameters possible which will give the desired results in an economical and timely fashion. Optimized parameters provide best results in minimum possible time and save resources. The earlier full factorial design was used which give the all possible combinations of factors and the number of experiments, in this case, were very large. Thus only a small collection of all the possibilities could be selected, this is called as the partial factorial design. This method also has some limitations for the analysis of the end results which were removed by Taguchi's design of experiments which introduced us to the concept of orthogonal arrays.

In our experiment, we will be using Taguchi method for finding the best set of process parameters. We have selected 4 factors with each factor having 3 levels. These factors are peak current, pulse on time, pulse off time, and gap voltage. Response parameters will be surface roughness, tool wear rate, and material removal rate. L27 orthogonal array will be used to find the optimum setting of the process parameters. It is assumed that there will be no interaction among the process parameters.

S.No.	Process Parameter	Level 1	Level 2	Level3
1.	Peak Current	4A	8A	12A
2.	Pulse On Time	100µs	150µs	200µs
3.	Pulse Off Time	20µs	40µs	6µs
4.	Gap Voltage	10V	20V	30V

Table -6. Process parameters and their Levels

Thus there will be 27 experimental runs and the output parameter will be noted for each experimental run.

In Taguchi design, various factors influence the quality of the product. These factors are the design factors and noise factors. Design factors are those which are controlled by the designer and noise factors include uncontrollable factors like environmental factors. A signal to noise ratio is a guide to assess the quality of the manufacturing process. A signal shows a desirable value and noise show an undesirable value, where the signal to noise ratio represents distribution around the preferred value. In the study of Signal to noise, there are three types of the performance categories. Those are lower the better, higher the better and nominal the better.

CHAPTER 7: PROPOSED WORKPLAN AND TIMELINES

Activities	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1.Literature Review									
2.Identifying the problem									
3.Material selection									
4.Tool Fabrication									
5.Experimental work									
6. Analysis of the data									
7. Preparation of report									

Table 7- Proposed Work plan.

The research work started in the August 2017 and will complete in April 2018. As usual Literature survey and Identifying the problem took most of the time, it included studying various research paper and finding the research gap. Material selection was also a crucial step which has been completed. AZ31 a magnesium alloy is selected as the workpiece and tool material is Titanium. Fabrication of the tool will be done in the month of December and all experimental work will be done in January 2018 following analysis of data in the following month. Preparation of the final report and research paper is supposed to consume last two month of the session.

CHAPTER 8: EXPECTED OUTCOMES

Outcomes after the successful completion of this research will be-

- Successful machining of the AZ31 with the Titanium electrode.
- Optimized process parameters for the machining of AZ31.
- Successful coating of the workpiece with EDM which will help in better surface finish and increase the corrosion resistance of the workpiece.

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