Thesis

On

Effect of EDM process parameters on Al-ZrO_2 composite using Taguchi orthogonal Array Design

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

Master of Engineering

IN

PRODUCTION & INDUSTRIAL ENGINEERING

Submitted By:

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CERTIFICATE

It is Certified that this Thesis Report entitled "**Effect of EDM process parameters on Al-ZrO2 composite**" submitted by **Mr. Ramanjeet Singh**, in the partial fulfilment of the requirement, for the award of **Master Of Engineering (Production And Industrial Engineering)** Degree of **Thapar University, Patiala** is a record of student's own study carried under our supervision. This report is of desired standard and has not been submitted in any other University or Institute for the award of the degree.

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Place: Patiala

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ABSTRACT

In the process technology, as there are numerous advances at rapid rate, a large number of new materials are being developed everyday. These materials have the combination of properties, like light weight, corrosive resistance, high strength etc. which is most easy to obtain in general. The important aspect is that they satisfy the demand of today's industry, but the major problem is that it is very difficult to machine. So, in order to manipulate them, newer machining methods have been developed. These methods are more efficient than the conventional one's. Electric discharge machining is one of the most widely used methods among the new techniques. The main reason behind the popularity of Electric Discharge Machining is that its capability of machining the hard material and complicated shapes.

The intent of present study is to study the effect of process parameters on Surface Roughness , Material Removal Rate and Tool Wear Rate in electric discharge machining of aluminium alloy LM13+5%ZrO_2 metal matrix composites. The design of experiments approach using Taguchi method is used to optimise the parameters like Peak Current, Tool Material and Pulse-On Time in EDM of Al Metal Matrix composites for minimum Surface Roughness and Tool Wear Rate, and maximum Material Removal Rate. T-3822M electric discharge machine manufactured by VICTORY ELECTROMECH is used to machine the Metal Matrix Composite. Experiments are conducted based on the Taguchi parameter design by varying the Peak Current, Pulse On-Time and Tool Material. Signal-to-noise ratio and analysis of variance are used to study the effect of parameters on the Surface Roughness, Material Removal Rate and Tool Wear Rate.

ABBREVATIONS

ANOVA	Analysis of Variance
DOF	Degree of Freedom
EDM	Electric Discharge Machining
MRR	Material Removal Rate
TWR	Tool Wear Rate
SR	Surface Roughness
SEM	Scanning Electron Microscope
EDS	Energy Dispersive Spectrometer
XRD	X-Ray Diffraction
S/N Ratio	Signal to Noise Ratio
MMCs	Metal Matrix Composite
RC	Relaxation Circuit

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INTRODUCTION

1.1 Metal Matrix Composites

1.1.1 Introduction

Metal composite materials have found application in many areas of daily life for quite some time. Often it is not realized that the application makes use of composite materials. These materials are produced *in situ* from the conventional production and processing of metals. Here, the Dalmatian sword with its meander structure, which results from welding two types of steel by repeated forging, can be mentioned. Materials like cast iron with graphite or steel with high carbide content, as well as tungsten carbides, consisting of carbides and metallic binders, also belong to this group of composite materials. For many researchers the term metal matrix composites is often equated with the term light metal matrix composites (MMCs). Substantial progress in the development of light metal matrix composites has been achieved in recent decades, so that they could be introduced into the most important applications. In traffic engineering, especially in the automotive industry, MMCs have been used commercially in fiber reinforced pistons and aluminum crank cases with strengthened cylinder surfaces as well as particle-strengthened brake disks.

These innovative materials open up unlimited possibilities for modern material science and development; the characteristics of MMCs can be designed into the material, custom-made, dependent on the application. From this potential, metal matrix composites fulfill all the desired conceptions of the designer. This material group becomes interesting for use as constructional and functional materials, if the property profile of conventional materials either does not reach the increased standards of specific demands, or is the solution of the problem. However, the technology of MMCs is in competition with other modern material technologies, for example powder metallurgy. The advantages of the composite materials are only realized when there is a reasonable cost – performance relationship in the component production. The use of a composite material is obligatory if a special property profile can only be achieved by application of these materials.

The possibility of combining various material systems (metal – ceramic – nonmetal) gives the opportunity for unlimited variation. The properties of these new materials are basically determined by the properties of their single components. Figure 1.1 shows the allocation of the composite materials into groups of various types of materials. The reinforcement of metals can have many different objectives. The reinforcement of light metals opens up the possibility of application of these materials in areas where weight reduction has first priority. The precondition here is the improvement of the component properties. The development objectives for light metal composite materials are:

- Increase in yield strength and tensile strength at room temperature and above While maintaining the minimum ductility or rather toughness,
- Increase in creep resistance at higher temperatures compared to that of Conventional alloys,
- Increase in fatigue strength, especially at higher temperatures,
- Improvement of thermal shock resistance,
- Improvement of corrosion resistance,
- Increase in Young's modulus[1].

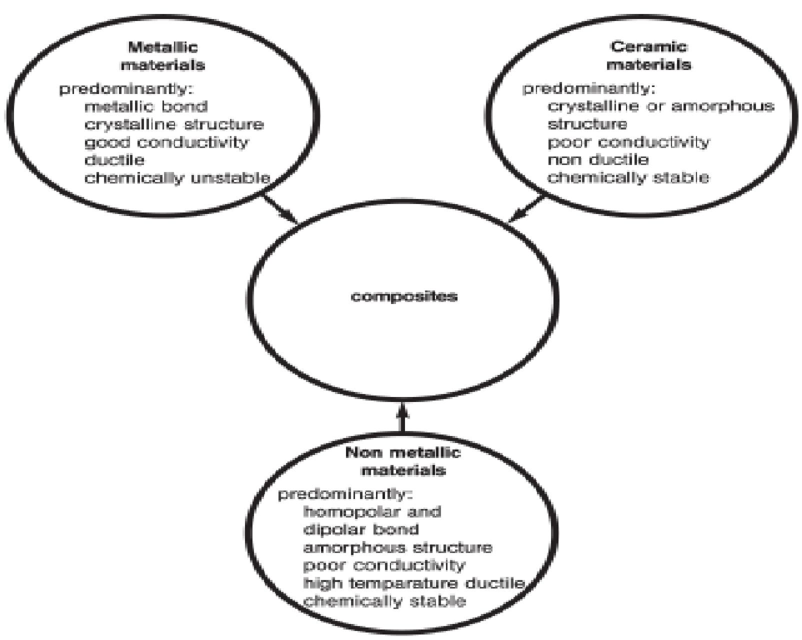


Fig. 1.1 Classification of the composite material within the group of materials[1]

1.1.2. Types of MMC

Metal-matrix composites are generally distinguished by characteristics of the reinforcement.

- Continues Fiber (multi- and monofilament)
- Short fiber (whisker)
- Particle

Table 1.1 shows example of some important reinforcements used in metal-matrix composites. These are categorized by the diameter and aspect ratio (length/diameter) of the reinforcement.

The aspect ratio of the reinforcement is an important quantity, because the degree of load transfer from the matrix to the reinforcement is directly proportional to the reinforcement aspect ratio. Thus, continuous fibers typically provide the highest degree of load transfer, because of their very high aspect ratio, which results in a significant amount of strengthening along the fiber direction. Particle or short fiber reinforced metals have a much lower aspect ratio, so they exhibit lower strengths than their continuous fiber counterparts, although the properties of these composites are much more isotropic. Figure 1.2 shows Schematic presentation of three shapes of metal matrix composite materials

Table 1.1 Typical Reinforcements Used in Metal-Matrix Composites[1]

Type	Aspect ratio	Diameter, μm	Examples
Particle	~ 1-4	1-25	SiC, Al_2O_3, BN, B_4C
Short fiber or whisker	~10-1000	0.1-25	SiC, Al_2O_3, Al_2O_3+SiO_2, C
Continuous fiber	> 1000	3-150	SiC, Al_2O_3, C, B, W

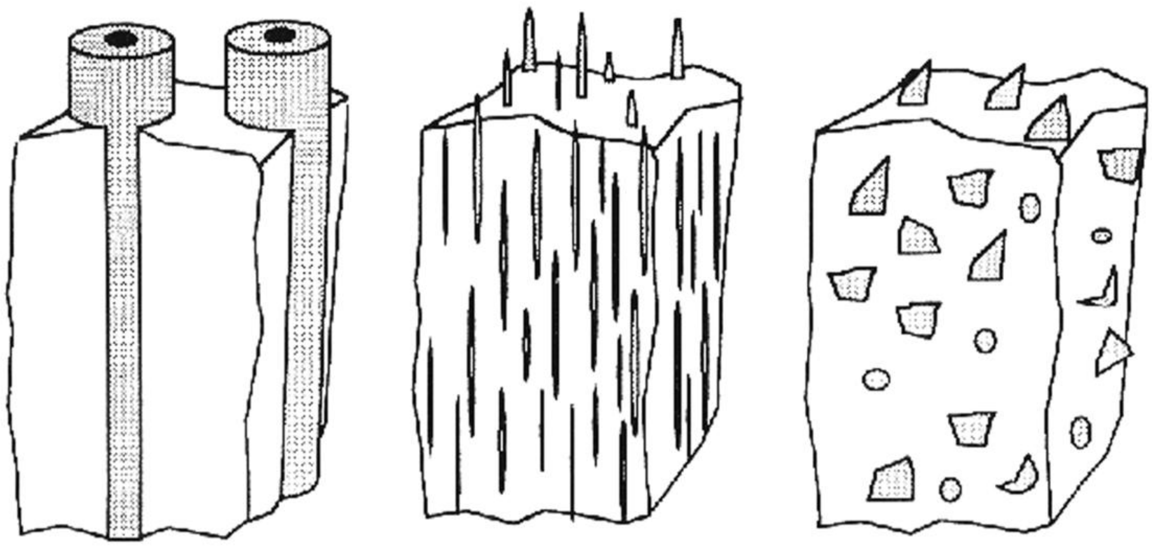


Fig. 1.2 Schematic presentation of three shapes of metal matrix composite materials [1]

1.1.3. Advantages of MMCs

The major advantages of MMCs compared to unreinforced materials are as follows:

- Greater strength
- Improved stiffness
- Reduced density(weight)
- Improved high temperature properties
- Controlled thermal expansion coefficient
- Thermal/heat management
- Enhanced and tailored electrical performance
- Improved abrasion and wear resistance
- Control of mass (especially in reciprocating applications)
- Improved damping capabilities.[2]

These advantages can be quantified for better appreciation. For example, elastic modulus of pure aluminium can be enhanced from 70GPa to 240GPa by reinforcing with 60 vol.% continuous aluminum fibre. On the other hand incorporation of 60 vol% alumina fibre in pure aluminium leads to decrease in the coefficient of expansion from 24 ppm/°C to 7 ppm/°C. Similarly it is possible to process Al-9% Si-20 vol% SiCp composites having wear resistance equivalent or better than that of grey cast iron. All these examples illustrate that it is possible to alter several technological properties of aluminium/aluminium alloy by more than two–three orders of magnitude by incorporating appropriate reinforcement in suitable volume fraction.

MMC material systems offer superior combination of properties (profile of properties) in such manner that today no existing monolithic material can rival. Over the years, MMCs have been tried and used in numerous structural, non-structural and functional applications in different engineering sectors. Driving force for the utilisation of AMCs in these sectors include performance, economic and environmental benefits. The key benefits of MMCs in transportation sector are lower fuel consumption, less noise and lower airborne emissions. With increasing stringent environmental regulations and emphasis on improved fuel economy, use of MMCs in transport sector will be inevitable and desirable in the coming years.

MMCs are intended to substitute monolithic materials including aluminium alloys, ferrous alloys, titanium alloys and polymer based composites in several applications. It is now recognized that in order MMCs substitution for monolithic materials in engineering system to be wide spread, there is a compelling need to redesign the whole system to gain additional weight and volume savings. In fact according to the UK Advisory Council on Science and Technology, MMCs can be viewed either as a replacement for existing materials, but with superior properties, or as a means of enabling radical changes in system or product design. Moreover, by utilising near-net shape forming and selective-reinforcement techniques MMCs can offer economically viable solutions for wide variety of commercial applications.

Recent successes in commercial and military applications of MMCs are based partly on such innovative changes made in the component design. Lack of knowledge and information about utilisation possibilities, service properties and material producers have hindered the wider usage of MMCs. Recognising these peripheral and extraneous difficulties, MMCs community in USA and Europe are pursuing consortium and networking approaches to implement the applications of MMCs in everyday societal use. In this article, overview is given on the current state of art on metal matrix composites with regard to processing, microstructure, properties and applications of AMCs. Challenges and opportunities for the intense use of MMCs are also outlined.[2]

1.2. Machining of MMCs

Metal Matrix Composites (MMCs) have proved to be extremely difficult to machine using conventional manufacturing processes due to heavy tool wear caused by the presence of the hard reinforcement. MMCs are machined easily by non-conventional manufacturing processes without any tool wear and material removal rate (MRR) is also higher. Now a days non-conventional machining is more popular in MMCs than conventional machining. The different machining processes used MMCs are given below:

2.1 Abrasive Water Jet machining (AWJM)

2.2 Laser machining

2.3 Electro discharge machining (EDM)

1.3 Electro Discharge Machining (EDM)

1.3.1. Introduction

Electro discharge machining (EDM) is an electro-thermal non-traditional machining process, where electrical energy is used to generate electrical spark material removal mainly occurs due to thermal energy of the spark.

EDM is mainly used to machine difficult-to-machined materials and high strength temperature resistant alloys. EDM can be used to machine difficult geometries in small batches or even on job-shop basis. Work material to be machined by EDM has to be electrically conductive.[3]

1.3.2. History of EDM

In 1770, English physicist Joseph Priestley studied the erosive effect of electrical discharges. Furthering Priestley's research, the EDM process was invented by two Russian scientists, Dr. B. R. Lazarenko and Dr. N. I. Lazarenko, in 1943. In their efforts to exploit the destructive effects of an electrical discharge, they developed a controlled process for machining of metals. Their initial process used a spark machining process, named after the succession of sparks (electrical discharges) that took place between two electrical conductors immersed in a dielectric fluid. The discharge generator effect used by this machine, known as the Lazarenko circuit, was used for many years in the construction of generators for electrical discharge. Since then, EDM technology has developed rapidly and become indispensable in manufacturing application such as die and mould making, micro-machining prototyping, etc. In 1950s the RC(resistance-capacitance) relaxation circuit was introduced, in which provided the first consistent dependable control of pulse times and also a simple servo control circuit to automatically find and hold a given gap between the electrode (tool) and the workpiece. In the 1980s, CNC EDM was introduced which improved the efficiency of the machining operation.[4]

1.3.3. Principle of EDM

In this process the metal is removing from the work piece due to erosion case by rapidly recurring spark discharge taking place between the tool and work piece. Show the mechanical set up and electrical set up and electrical circuit for electro discharge machining. A thin gap about 0.025mm is maintained between the tool and work piece by the servo system shown in fig 2.1. Both tool and work piece are submerged in a dielectric Fluid. Kerosene/EDM oil/deionized water is very common type of liquid dielectric although gaseous dielectrics are also used in certain cases.

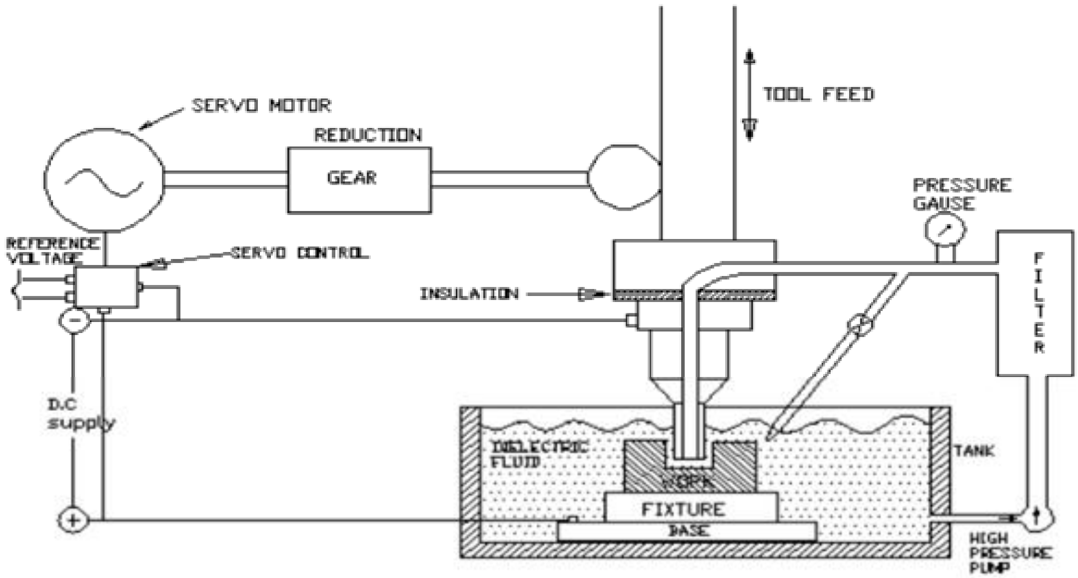


Fig. 1.3 set up of electrical discharge machining[3]

This fig. 1.3 is shown the electric setup of the Electric discharge machining. The tool is mead cathode and work piece is anode. When the voltage across the gap become sufficient high it discharge through the gap in the form of the spark in interval of from 10 of micro seconds and positive ions and electrons are accelerated, producing a discharge channel that become conductive. It is just at this point when the spark jumps causing collisions between ions and electrons and creating a channel of plasma. A sudden drop of the electric resistance of the previous channel allows that current density reaches very high values producing an increase of ionization and the creation of a powerful magnetic field. The moment spark occurs sufficiently pressure developed between work and tool as a result of which a very high temperature is reached and at such high pressure and temperature that some metal is melted and eroded.

Such localized extreme rise in temperature leads to material removal. Material removal occurs due to instant vaporization of the material as well as due ton melting. The molten metal is not removed completely but only partially.

As the potential difference is withdrawn as shown in fig. 1.4, the plasma channel is no longer sustained. As the plasma channel collapse, it generates pressure or shock waves, which evacuates the molten material forming a crater of removed material around the site of spark.

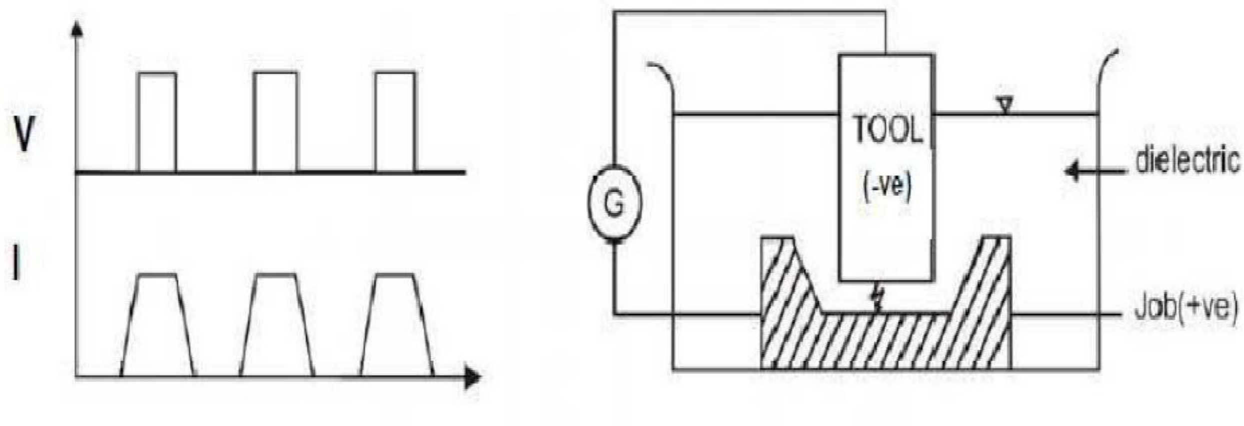


Fig.1.4 **Working principle of EDM process[3]**

1.3.4. Types of EDM

Basically, there are two types of EDM

1.3.4.1. Die-sinking

1.3.4.2. wire-cut

1.3.4.1. die-sinking

In the sinker EDM machining process, two metal parts submerged in an industrial liquid are connected to a source of current which is switched on and off automatically depending on the parameters set on the controller. When the current is switched on, an electric tension is created between the two metal parts. If the two part are brought together to within a fraction of an inch. The electrical tension is discharged and spark jumps across. Where it strikes, the metal is heated up so much that it melts. Sinker EDM, also called cavity type EDM or volume EDM consist of an electrode and workpiece submerged in an insulating such as,more typically, oil or, less frequently, other dielectic fluids. The electrode and workpiece are connected to a suitable power supply. The power supply generates an electrical potential between the two parts. As the electrode approaches the workpiece, dielectric breakdown occurs in the fluid, forming a plasma channel and a small spark jumps.

These sparks usually strike one at a time because it is very unlikely that different locations in the inter-electrode space have the identical local electrical characteristics which would enable a spark to occur simultaneously in all such locations. These sparks happen in huge numbers at seemingly random locations between the electrode and the workpiece. As the base metal is erod e machine so that the process can continue uninterrupted. Several hundred thousand sparks occurs per second, with the actual duty cycle carefully controlled by the setup parameters.

1.3.4.2. wire-cut

Wire EDM Machining (also known as spark EDM) is an electro thermal production process in which a thin single-stand metal wire (usually brass) in conjunction with de-ionized water (used to conduct electricity) allows the wire to cut through metal by the use of heat from electrical sparks. A thin single stand metal wire, usually brass, is fed through the workpiece, submerged in the tank of dielectric fluid, typically deionized water. Wire-cut EDM is typically used to cut plates as thick as 300mm and to make punches, tools and dies from the hard metal that are difficult to machine with other methods.

Wire-cutting EDM is commonly used when low residual stresses are desired, because it does not require high cutting forces for removal of material. If the energy/power per pulse is relatively low (as in finishing operations), little change in the mechanical properties of the material is expected due to these low residual stresses, although material that hasn’t been stress-relieved can distort in the machining process.Due to the inherent properties of the process. Wire EDM can easily machine complex parts and precision component out of hard conductive materials.[3]

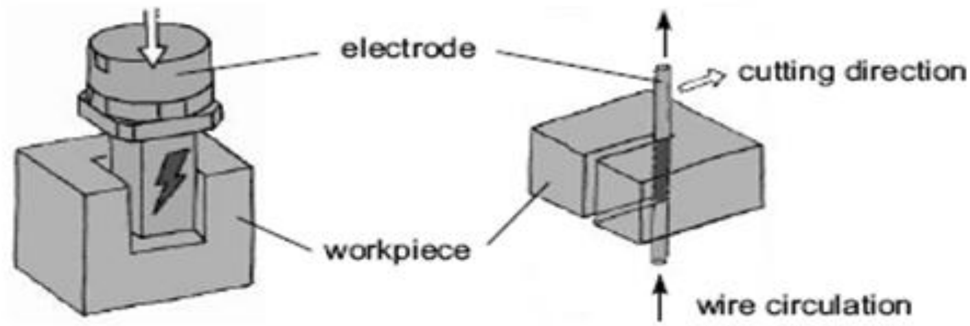


Fig. 1.5 Die sinking & Wire cut EDM process[3]

1.3.5 Important parameters of EDM

- **Polarity:** polarity refers to the direction of current flow in relation to the electrode. The polarity normally used is normal polarity in which the tool is negative and workpiece is positive. Sometimes reverse polarity can be used depending upon the requirement, where tool is positive and workpiece is negative. The reverse polarity of the workpiece has an inferior surface roughness than that under normal polarity in EDM.

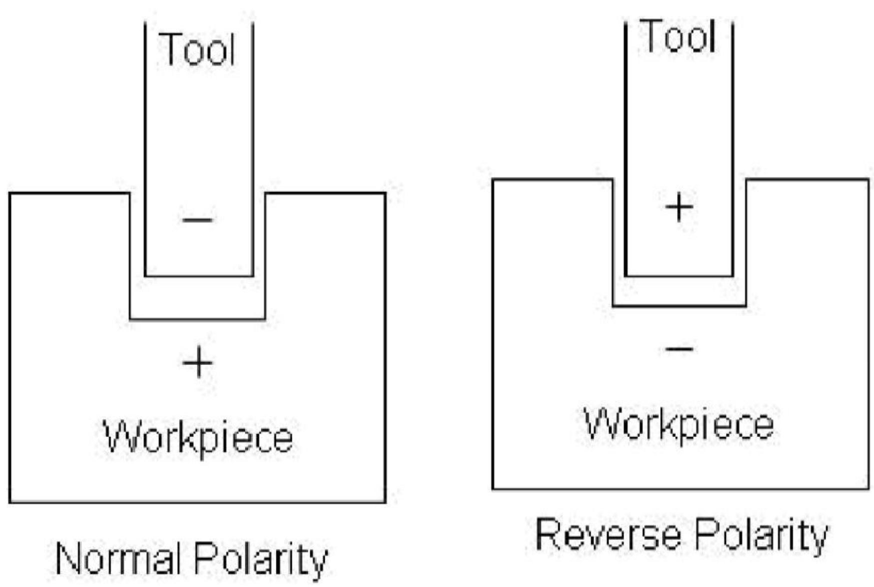


Fig. 1.6 set up for different polarities[3]

- **Current**: passing the gap creates high temperatures causing material evaporation at both electrode spots. As the electron processes show quicker reaction, the anode material is worn out predominantly. This causes minimum wear to the tool electrodes and become of importance under finishing operations with shorter on-times. However while longer discharges, the early electron process predominance changes to positron process, resulting in high tool wear.
- **Spark on-time** (pulse time or ton): is the duration of time (μs) the current is allowed to flow per cycle. All the work done during on-time, the duration of these pulses and the no of cycles per second are important. Material removal is directly proportional to the amount of energy applied during this on-time. This energy is really controlled by the peak current and the length of the on-time. Excessive on-times can be counter productive when the optimum on-time for each electrode-work material combination is exceeded, material rate starts to decrease.
- **Spark off-time** (pause time or toff): is the duration of time (μs) between the Sparks (that is to say, on-time). The cycle is completed when sufficient off-time is allowed before the start of the next cycle. This time allows the molten material to solidify and to be wash out of the arc gap. This parameter is to affect the speed and the stability of the cut. Shorter the off-time, the faster will be the machining operation. However, if the off-time is too short, the ejected workpiece material will not be swept away by the flow of the dielectric and the fluid will not be deionized. This will cause the next spark to be unstable. Unstable conditions cause erratic cycling and retraction of the advancing servo. This slows down cutting more than long, stable off-times. Off-times must be greater than the deionization time to prevent continued sparking at one point.
- **Arc Gap** (or gap): the arc gap is the distance between the electrode and Workpiece, during the process of EDM. It may be called as spark gap. The servo feed system is used to control the spark gap at a proper width. Mostly electro-mechanical (DC or stepper motors) and electro-hydraulic systems are used, and are normally designed to respond to average gap voltage. If the measured average gap voltage is higher than the servo reference voltage preset by the operator, the feed speed increases. On the contrary, the feed speed decrease or the electrode is

retracted when the average gap voltage is lower than the servo reference voltage, which is the case for smaller gap widths resulting in a smaller ignition delay. Therefore short-circuits caused by debris particles and humps of discharge craters can be avoided. Also quick changes in the working surface area, when tool electrode shapes are complicated, does not result in hazardous machining. In some cases, the average ignition delay time is used in place of the average gap voltage to monitor the gap width. (fig no:-1.3)

- **Peak Current:** this is the amount of power used in discharge machining, measured in units of amperes and the most important parameter in EDM. During each on-time pulse, the current increases until it reaches a preset level, which is expressed as the peak current. Higher currents will improve MMR but at the cost of TWR and surface finish.
- **Duty cycle (τ):** it is the percentage of the on-time relative to the total cycle Time. This parameter is calculated by dividing the on-time by the total cycle time (on-time pulse off-time)

$$\tau = \frac{\text{Ton}}{\text{Ton+Toff}}$$

- **Voltage (V):** it is a potential that can be measure by the volt it is also effect to the material rate and allowed to per cycle.[3,5]

1.3.6 Dielectric fluid

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

The dielectric fluid has the following functions:

(a) It helps in initiating discharge by serving as a conducting medium when ionized and conveys the spark. It concentrated the energy to a very narrow region.

(b) It helps in quenching the spark, cooling the work, tool electrode and enables the arcing to be prevented.

(c) It carries away the eroded metal along with it.

(d) It acts as the coolant in quenching the sparks.

The electrode wear rate, MMR and other characteristics are also influenced by the dielectric fluid

1.3.7. Type of flushing:

It is basic requirement of dielectric that it should maintain its strength (insulating properties) during its whole operation. There is no problem at the start of EDM, but after discharge the debris are produced in the gap reduce the dielectric strength, which cause unwanted discharges which can damage to both tool and workpiece. Hence effective flushing is required to remove unwanted debris from the gap. TWR and MMR are affected by the type of dielectric and the method of its flushing. in EDM, flushing can be achieved by following methods:

1.3.7.1. Suction flushing

In this, dielectric may be sucked through either the workpiece or the electrode. This technique is employed to avoid any tapering effect due to sparking between machining debris and the side walls of the electrodes. Suction flushing through the tool rather than through the workpiece is more effective.

1.3.7.2 Injection flushing

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

1.3.7.3 Side Flushing

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

1.3.7.4. Flushing by dielectric pumping

This method has been found particularly suitable in deep hole drilling. Flushing is obtained by using the electrode pulsation movement. When the electrode is raised, clean dielectric is sucked into mix with contaminated fluid, and as the electrode is lowered the particles are flushed out[3,5].

1.3.8. Characteristics of EDM

EDM specification by mechanism of process, material removal rate and other functions that shown in table 1.2

Table 1.2 Specification of EDM [5]

Mechanism of process	Controlled erosion (melting and evaporation) through a series of electric spark
Spark gap	0.010-0.500 mm
Spark frequency	200-500 KHz
Peak voltage across the gap	30-250 V
Metal removal rate (max.)	5000mm^3/min
Specific power consumption	2-10W/mm^3/min
Dielectric fluid	EDM oil, Kerosene liquid paraffin, silicon oil, deionized water etc.
Tool Material	Copper, Brass, Graphite, Ag-W alloys, Cu-W alloys
MRR/TWR	0.1-10
Material that can be machined	All conducting metals and alloys.
Shapes	Microholes, narrow slots, blind cavities

Limitations	High specific energy consumption, non-conducting materials can’t machined

1.3.9. Tool Material

Tool material should be such that it would not undergo much tool wear when it is impinged by positive ions.Thus the localized temp. Rise has to be less by tailoring or properly choosing its properties or even when temp. Increases, there would be less melting. Further, the tool should be easily workable as intricate shaped geometric features are machined in EDM.

Thus the required characteristics of electrode material are:

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

The different electrode materials which are commonly used in the industry are:

1. Graphite
2. Copper
3. Tellurium copper(99%cu+0.5% tellurium)
4. Brass
5. Aluminum

1.3.10. Design variable

1.3.10.1. Design parameters:-

1. Material removal rate(MMR)
2. tool wear rate(TWR)
3. Surface Roughness (SR)

1.3.10.2. Machining parameter:-

1. Discharge current (Ip)
2. Pulse on time (Ton)
3. Diameter of U-shaped tool

1.3.10.3 Constant parameters:-

1. Duty cycle
2. voltage
3. Flushing pressure
4. polarity

1.3.11. Applications of EDM

1. The EDM process is most widely used by the mould-making tool and die industries, but is becoming a common method of making prototype and production parts, especially in the aerospace, automobile and electronics industries in which production quantities are relatively low.
2. It is used to machine extremely hard material that are difficult to machine like alloys, tool steel, tungsten carbides etc.
3. It is used for forging, extrusion, wire drawing and thread cutting.
4. It is used for drilling of curved holes.
5. It is used for internal thread cutting and helical gear cutting.
6. It is used for machining sharp edges and corners that cannot be machined effectively by other machining processes.
7. Higher tolerance limits can be obtained in EDM. Hence areas that require higher surface accuracy use the EDM process.

8. Ceramic material that are difficult to machine can be machined by EDM process.
9. EDM has also made its presence felt in the new fields such as sports, medical and surgical, instruments, opticals, including R&D areas.
10. It is promising technique to meet increasing demand for smaller components usually highly complicated, multi-functional parts used in the field of micro-electronics.[3,5]

1.3.12. Advantages of EDM

(a) Any material that is electrically conductive can be cut using the EDM process.

(b) Hardened workpieces can be machined eliminating the deformation caused by heat treatment.

(c) X, Y and Z axes movements allow for the programming of complex profiles using simple electrode.

(d) Complex dies sections and molds can be produced accurately, faster and at lower costs. Due to the modern NC control system on die sinking machines, even more complicated workpieces can be machined.

(e) The high degree of automation and the use of tool and workpiece changer allow the machines to work unattended for overnight or during the weekends.

(f) Forces are produced by EDM-process and that, as already mentioned, flushing and hydraulic forces may become large for some work piece geometry. The large cutting forces of the mechanical material removal processes, however, remain absent.

(g) Thin fragile sections such as webs or fins can be easily machined without deforming the part.[3,5]

1.3.13 Limitations of EDM

(a) The need for electrical conductivity:- to be able to create discharges, the workpiece has to be electrically conductive, isolators, like plastics, glass and most ceramics, can not be machined by EDM, although some exception like for example diamond is known. Machining of partial conductors like Si semi-conductors, partially conductive ceramics and even glass is also possible.

(b) Predictability of the gap:- the dimensions of the gap are not always easily predictable, especially with intricate work piece geometry. In these cases, the flushing conditions and the contamination state of differ from the specified one. In the case of die-sinking EDM, the tool wear also contributes to the deviation of the desired work piece geometry and it could reduce the achievable accuracy. Intermediate measuring of the work piece or some prelimary tests can often solve the problems.

(c) Low material removal rate:- the material removal of the EDM process is rather low, especially in the case of die-sinking EDM where the total volume of a cavity has to be removed by melting and evaporating the metal. With wire-EDM only the outline of the desired work piece shape has to be machined. Due to the low material removal rate, EDM is principally limited to the production of small series although some specific mass production applications are known.

(d) Optimization of the electrical parameters:- the choice of the electrical parameters of the EDM-process depends largely on the material combination of electrode and workpiece and EDM manufactures only supply these parameters for a limited amount of material combinations. When machining special alloys, the user has to develop his own technology.[3,5]

CHAPTER -2

LITERATURE REVIEW

2.1. INTRODUCTION

A large work has been done on different aspects of EDM. In this chapter select few research paper related to EDM with effect of metal MRR, TWR, surface roughness (SR) of workpiece material, we are broadly classified all the paper to different category, i.e. paper related to material related to workpiece or tool, tubular electrode, EDM with polarity changing, EDM vs ECDM..

2.1.1. Workpiece and tool material:-

P.N Singha, K. Raghukandana *et* al. [2004] uses unconventional machining techniques in shaping aluminium metal matrix composites (Al-MMC). They generated interest in the manufacturing of complicated die contours in these hard materials to a high degree of accuracy and surface finish is difficult. Electrical discharge machining (EDM) is an important process for machining difficult-to-machine materials like metal matrix composites. Among the many unconventional processing techniques, EDM has proved itself to be one among the effective tool in shaping such difficult-to-machine materials. The objective of this work is to investigate the effect of current (C), Pulse ON-time (P) and flushing pressure (F) on metal removal rate (MRR), tool wear rate (TWR), taper (T), radial overcut (ROC), and surface roughness (SR) on machining as-cast Al-MMC with 10% SiCP reinforcement. At the end of experiment it is concluded that This work evaluates the feasibility of machining Al–10% SiCP MMCs. MRR was found to be higher for larger current and pulse ON-time settings at the expense of tapercity, radial overcut and surface finish and TWR was also found to be higher, larger than the MRR, for larger current settings. At higher current and ON-time ratings, the dimensional accuracy is affected. Flushing pressure of the dielectric has considerable effect on the MRR and TWR [6].

S. Sarkar, S. Mitra *et* al. [2004] study the wire electro-discharge machining (EDM) of γ-titanium alumide alloys, an extensive research study has been carried out with an aim to select the optimum cutting condition with an appropriate wire offset setting in order to get the desired surface finish and dimensional accuracy. By experimental investigation on single pass cutting of wire electrical discharge machining of γ-TiAl alloy has been carried out. The process has been successfully modeled using additive model. The predicted response parameters from the model agreed quite well with that of the experimental result. Based on the developed model influence of the various process parameter on the machining criteria was observed. It is noted that both surface roughness as well as dimensional deviation is independent of the pulse off time. This aspect is very important as under certain critical machining condition pulse off time can be varied as per requirement to achieve between stability and accuracy without affecting the dimensional accuracy and surface finish [7].

P.M. George, B.K. Raghunath *et* al. [2004] determine the optimal setting of the process parameters on the electro-discharge machining (EDM) machine while machining carbon–carbon composites. The parameters considered are pulse current, gap voltage and pulse-on-time; whereas the responses are electrode wear rate (EWR) and material removal rate (MRR). The optimal setting of the parameters are determined through experiments planned, conducted and analysed using the Taguchi method. This work shows optimisation of the machining parameters in the EDM machining of C–C composite using Taguchi method. The process variables affecting electrode wear rate and MRR, according to their relative significance, are *V*g, *I*p and Ton, respectively. Among the process parameters Ton is insignificant. The optimum machining conditions for electrode wear rate, with an expected reduction of 89.28% from the current average value of 0.056 mg/min, is *I*p = 1A, Ton = 150 µs and *V*g = 20V. Whereas the same for MRR, with an expected increase of 116.67% from the current average value of 0.09mm3/min, is *I*p = 9A, Ton = 750 µs and *V*g = 100V. The optimum conditions for the two response functions are different. It is shown that machining parameters set at their optimum levels can ensure significant improvement in the response functions [8].

Scott F. Millera, Albert J. Shiha *et* al. [2004] investigate the effect of spark on-time duration and spark on-time ratio, two important EDM process parameters, on the material removal rate (MRR) and surface integrity of four types of advanced material: porous metal foams, metal bond diamond grinding wheels, sintered Nd-Fe-B magnets, and carbon–carbon bipolar plates. They develop experimental procedure, during the wire EDM, five types of constraints on the MRR due to short circuit, wire breakage, machine slide speed limit, and spark on-time upper and lower limits are identified. An envelope of feasible EDM process parameters is generated for each work-material. Applications of such a process envelope to select process parameters for maximum MRR and for machining of micro features are discussed. This study also demonstrated the capability of wire EDM process to machine different advanced materials. Using traditional metal cutting methods, it is difficult to machine the metal foams without damaging the ligaments. The diamond grinding wheel is very difficult to machine to the precise shape. Sintered Nd-Fe-B magnet material is very brittle and easily chipped by using traditional machining methods. Carbon–carbon bipolar plate is delicate but can be machined easily by the EDM. The future research is to apply the envelope developed in this study for machining of miniature features and for high MRR EDM of advanced materials [9].

Ahmet and Ulas [2004] investigate the machining characteristics of AISI D5 tool steel in wire electrical discharge machining (EDM) process. The parameters such as open circuit voltage, pulse duration, wire speed and dielectric fluid pressure are changed to explore their effects on the surface roughness and metallurgical structure. Optical and scanning electron microscopy, surface roughness and micro-hardness tests are used to study the characteristics of the machined specimens. Result of this experiment is the thickness of the heat-affected zone or white layer on the surface is approximately proportional to the magnitude of the energy impinging on that surface. The density of cracks increase with increase in pulse duration and open circuit voltage. The surface roughness increased when the pulse duration and open circuit voltage are increased. The cutting surface of all specimens is harder than the bulk material because of white layer, while the heat affected zone is softer in quenched and tempered specimens because of overtempered martensite [10].

Y. W. Seo, D. Kim *et* al. [2007] drill the 15–35 volume% silicon carbide particulate (SiCp) reinforced Al359 metal matrix composite (SiCp/Al MMC) by electrical discharge machining (EDM) to compute the machinability and workpiece quality. The machining conditions are identified for both the machining performance and workpiece quality of the EDM process, including some aspects of material removal mechanisms, material removal rate (MRR), electrode tool wear, and subsequent drilled hole quality including surface texture and roundness by using surface profilometry, coordinate measuring machine (CMM), and scanning electron microscopy (SEM). Based on the results, it is conclude that optimal combinations of peak current and pulse-on-time exist to produce the maximum material removal rate. The MMR increase with increasing peak current and pulse-on-time up to an optimal value and after that decreases drastically. The MRR increases with increasing SiC particle percentage. The combination of high peak current and low pulse-on-time lead to larger tool wear. The average diameter error is proportional to pulse-on-time and peak current. Higher energy results in a rougher surface. Under coarse or rapid cutting condition, the machined surface is negatively skewed, due to the well-defined discontinuous patches of re-cast material, deep vacancies, and cracks on the re-cast layer [11].

S. Sarkar, M. Sekh *et* al. [2007] investigated on trim cutting of wire electrical discharge machining of γ-TiAl alloy which is carried out with a view to enhance the productivity while maintaining the desired surface finish and geometrical accuracy. This process is successfully modeled using RSM. Finally WEDM process is optimized using Minitab software. It is observed that lot of trial and error and manual turning are required to obtain the true optimal solution. Hence, a more formal and advanced approach based upon Pareto optimization algorithm is developed. It is observed that the developed pareto optimization strategy eliminates the guesswork and gives better result than desirability function approach. It is also seen that the surface quality decreases as the cutting speed increase and they varies almost linearly up to surface roughness value 1.22μm and cutting speed 13.88mm/min. beyond this value of cutting speed surface roughness deteriorates drastically.This research approach is extremely useful for maximizing the productivity while maintaining surface finish and geometrical accuracy within desired limit [12].

K. Kanlayasiria, S. Boonmungb [2007] investigate the effects of machining parameters on surface roughness of wire EDMed DC53 die steel. The investigated machining parameters are pulse-on time, pulse-off time, pulse-peak current, and wire tension. Analysis of variance (ANOVA) technique is used to find out the parameters affecting the surface roughness. Assumptions of ANOVA are discussed and then examined through residual analysis. Quantitative testing methods on residual analysis were employed in place of the typical qualitative testing techniques. It is observed that pulse-on time and pulse-peak current were significant variables to the surface roughness of wire-EDMed DC53 die steel. The surface roughness of the test specimen became larger when these two parameters were increased [13].

Ahmad Rani, Alexis Moua *et* al. [2008] check the possibility of machining using Electro-discharge machining by varying various machining parameters. And they Results that aluminium metal matrix composite can be effectively EDM machined at low peak current at certain ON-time and OFF-time. It is concluded that Aluminum metal matrix composite Al-A242/30% Al_2O_3 material can be machined by EDM using electrolyte copper to produce good result at low peak current. At high peak current white layer and micro-cracks tends to form on parts of the surface. Surface roughness and surface morphology deteriorates at high peak current [14].

Yan Lin, Yuan Chen *et* al. [2008] investigate the machining of cemented tungsten carbides graded K10 and P10 by electrical discharge machining (EDM) using an electrolytic copper electrode. The machining parameters of EDM are varied to explore the effects of electrical discharge energy on the machining characteristics, such as material removal rate (MRR), electrode wear rate (EWR), and surface roughness. Moreover, the effects of the electrical discharge energy on heat-affected layers, surface cracks and machining debris were also determined. It is observed that increasing the energy density of EDM (large peak current and short pulse duration) increased the MRR and EWR of cemented tungsten carbides. MRR of P10 cemented tungsten carbide exceeds that of grade K10 under particular EDM conditions. The debris diameter increased with the electrical discharge energy that was conducted into the machining gap between the workpiece and the electrode.The machined surface of the cemented tungsten carbide shows remarkable surface cracks when the peak current exceeded 1am. The depth of surface cracks increased with the peak current. The surface cracks on the P10 cemented tungsten carbide were perpendicular to the machined surface and extended into the base metal. Those of grade K10 grew parallel to the machined surface. The heat-affected zone of cemented tungsten carbide formed a softened layer with a thickness of about 200–300_m when the electrical discharge energy was high [15].

D Kanagarajan, R Karthikeyan *et* al. [2008] study the electro discharge machining (EDM) of WC/30%Co composites. In this experiment four design factors: electrode rotation (S), pulse on time (T), current (A), and flushing pressure (P) of EDM, are chosen as variables in order to study the process performance in terms of material removal rate (MRR) and surface roughness (Ra). from experiment it is observed that the factor C (peak current), factor S (electrode rotation), factor P (flushing pressure), and factor T (pulse on time) are the most influential parameters to affect MRR and Ra. The combination of low pulse time and high peak current, rotational speed, and flushing pressure yields more MRR and less Ra. A greater improvement in MRR is expected at still higher levels of current (25A), electrode rotation (150 r/min), pulse on time (500 ms), and flushing pressure (2.5 kg/cm2) of die electric fluid. The improvement in surface finish is also expected at higher levels of electrode rotation and flushing pressure. The cobalt has high thermal conductivity compared with the tungsten carbide. Cobalt is easily removed from the parent material, therefore, MRR is directly proportional to the %age of cobalt material [16].

Yan Lin, A Wang *et* al. [2009] Investigates the machining performance of conductive ceramics (Al_2O_3+ 30vol% TiC) by using electrical discharge machining (EDM). They select the EDM machining parameters such as machining polarity, peak current, auxiliary current with high voltage, pulse duration, no load voltage, and servo reference voltage to examine the effects on material removal rate (MRR), electrode wear rate (EWR), and surface roughness (SR). They adopt The L18 orthogonal array based on the Taguchi experimental method to determine EDM machining characteristics systemically, and the experimental data is statistically analyzed by analysis of variance (ANOVA). It is conclude that When the EDM process is used to machine a conductive ceramic, MRR increased with peak current and pulse duration. EWR increased with peak current, and declined with pulse duration. SR enlarged with peak current and pulse duration. Due to the promotion of material removal effects, discharge craters were deeper and broader. ANOVA and F test experimental data related to EDM essential machining parameters revealed that machining polarity (P) and peak current (Ip) significantly affected MRR. Experimental data analysis based on the Taguchi method indicated that machining polarity (P) and peak current (Ip) significantly affected EWR. Experimental data analysis based on the Taguchi method demonstrated that only peak current (Ip) significantly affected SR [17].

K. M. Patel, P. M. Pandey *et* al. [2009] Investigated the influence of parametric setting on machining performance during EDM of Al_2O_3/SiCw/TiC ceramic composite. In EDM, machining parameters determine the quality of surface produced. Second order regression model has been developed for predicting surface roughness (SR) in terms of machining parameters using the response surface methodology. Conclusion of this experiment is the two-stage effort of obtaining a SR model by RSM and optimization of this model by a trust region method have resulted in a fairly useful method of obtaining process parameters in order to attain the improved surface quality. The parameters discharge current, pulse-on-time, and dutycycles are primary factors affect the SR (Fig.2.1) of AlSiTi ceramic composite during EDM [18].

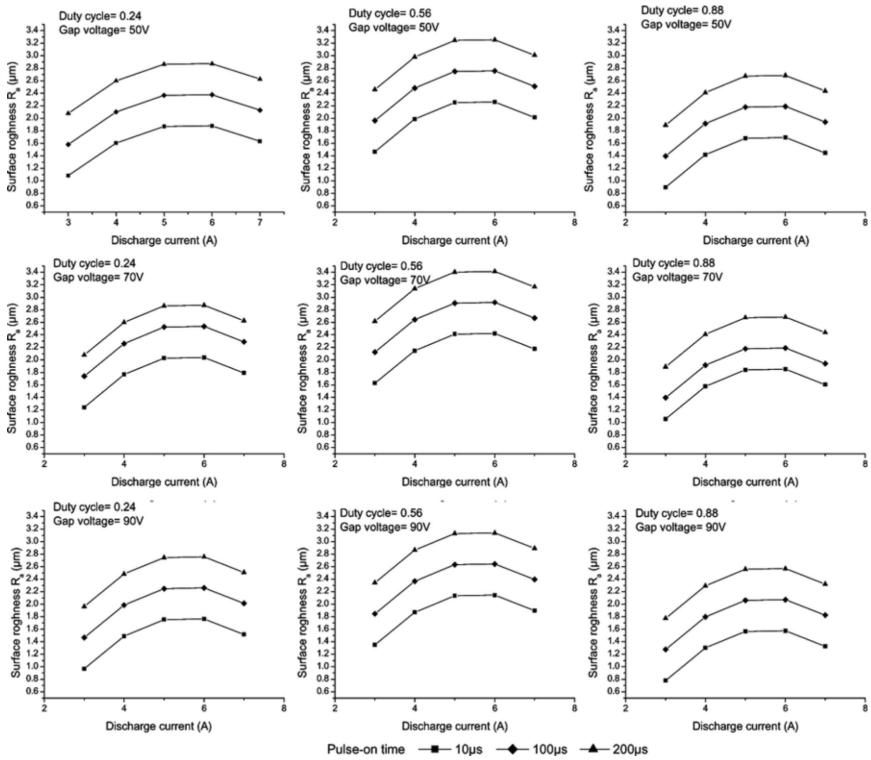


Fig. 2.1: Variation of surface roughness (SR) with discharge current at different values of duty cycle and gap voltage[18]

D. Bhaduri, A. S. Kuar *et* al. [2009] study the effects of EDM process parameters on material removal rate, electrode wear rate, radial overcut, and taper angle while machining TiN- Al2O3 composite. From experiment it is observed that during trial runs, the workpiece has been broken for pulse energy above 200 coulombs. MRR increases with increase in peak current and gap voltage, while with increase in pulse-on time, it reaches up to a maximum limit and then decreases. The effect of peak current is less on EWR, and duty cycle has almost no effect on it. EWR decreases with increase in pulse-on time and gap voltage. With increase in peak current, EWR at first increases and then decreases. ROC decreases with increase in pulse-on time and peak current; however, it at first decreases and then increases with increase in gap voltage. Taper angle also decreases with increase in peak current but increases with increase in gap voltage. With increase in pulse-on time, at first it has an increasing and then a decreasing trend. The whole experimental study indicates that EDM has a very good potential in machining of TiN–Al2O3 ceramic composite in some particular ranges of process parameters [19].

FW4 is a newly developed hot die material widely used in Forging Dies manufacturing. The right selection of the machining conditions is one of the most important aspects to take into consideration in the Electrical Discharge Machining (EDM) of FW4. **M.R.Shabgard, R.M.Shotorbani [2009]** develops mathematical models for relating the Material Removal Rate (MRR), Tool Wear Ratio (TWR) and surface roughness (Ra) to machining parameters (current, pulse-on time and voltage). It is observed that for all values of the peak current, surface roughness increases with the increase of the pulse-on time. The surface roughness first increases slightly with the voltage and then increases severely with further increase of the voltage. The MRR value increases with the increase of pulse-on time. With increase of pulse-on time, Tool Wear Ratio is decrease [20].

M. Kathiresan and **T. Sornakumar[2010]** develop a aluminum alloy-silicon carbide composites by using a new combination of vortex method and pressure die casting technique. They study the Electrical Discharge Machining (EDM) on aluminum alloy-silicon carbide composite work piece using a copper electrode in an electrical discharge machine. They observed that the MMR and the surface roughness are greatly affected by the current and percent weight silicon carbide. The surface finish improves with decrease in the current and increase in the percent weight of silicon carbide [21].

Nanimina, Abdul-rani *et* al. [2011] apply the Electro-Discharge machining on 30% (by volume) Al_2O_3 reinforced AMMC. They study the specific machining performance characteristics of AMMC reinforcement with 30% Al_2O_3 and compare with Al6061.the characteristics under study are material removal rate (MRR) and tool wear ratio (TWR). Key process parameters such as peak current, pulse and pulse duration (ON-time and OFF-time), are varied to determine the influence on the MRR and TWR of 30% Al_2O_3 reinforced AMMC. The feasibility of machining 30 vol% alumina particle reinforced aluminium composite by using EDM die-sinker machine with electrolytic copper electrode has been evaluated in terms of MMR and tool wear ratio and it has proven acceptable at low peak current, short ON-time and high OFF-time. However, EDM performance of machining AMMC is less effective compared to EDM of Al6061 peak current, ON-time which determine the spark energy are most important parameters influencing on output responses. It is observed from the result on the AMMC and Al 6061 that the increase peak current or ON-time leads to increase the spark energy and this result in faster machining speed. Tool wears rapidly for AMMC when OFF-time increases compared to Al6061 [22].

S. Venkat Prasat, R. Subramanian *et* al. [2011**]** investigates The process parameters on surface roughness (SR), material removal rate (MRR) and tool wear rate (TWR) in electric discharge machining (EDM) of aluminium-fly ash-graphite hybrid metal matrix composites. They applied design of experiments approach using Taguchi method to optimize the parameters like peak current, flushing pressure and pulse on time (Ton) in EDM of hybrid composites for minimum SR and TWR, and maximum MRR. They use the Electronica-Small die sinking electric discharge machine to drill holes in the hybrid composite workpiece. Using Taguchi parameter design they conduct the Experiments by varying the peak current, flushing pressure of dielectric fluid and Ton. Signal-to-noise ratio and use the analysis of variance to investigate the influence of parameters on the SR, MRR and TWR. They determined that peak current was the most significant parameter influencing the responses, followed by Ton and flushing pressure. And increase in the SR of hybrid composites with increases in peak current and Ton due to the generation of much larger and deeper craters on the drilled surface. SR also increases with an increase in flushing pressure. MRR increases almost linearly with increases of peak current, flushing pressure and Ton. There is an increase in TWR with increases in peak current and flushing pressure. However, when Ton was increased, there was a marginal decrease in the TWR due to formation of carbon deposits on the electrode. Multiple linear regression models were developed to predict the SR, MRR and TWR [23].

Trias A, Azli Y *et* al. [2011] predict of Material Removal Rate (MRR) in Electrical Discharge Machining (EDM) using Artificial Neural Network (ANN). They use Die sinking EDM process for copper-electrode and steel- workpiece. The aim of experiment is to develop a behavioral model using input-output pattern of raw data from EDM process experiment. The behavioral model is used to predict MRR and than the predicted MRR is compared to actual MRR value. The results show good agreement of predicting MRR between them [24].

2.1.2. EDM with tubular electrode

B. Mohan, A. Rajadurai *et* al. [2004] investigate the machining characteristics of SiC/6025Al composite using rotary electro-discharge machining (EDM) with a tube electrode(Fig.2.2). They use Brass as an electrode material to EDM SiC/6025Al composites. The observed values: material removal rate (MRR), Electrode wear rate (EWR) and surface roughness (SR) is used to evaluate machinability. Peak current, polarity, volume fraction of SiC reinforced particals, pulse duration, hole diameter of the tube electrode and speed of electrode rotation are used as the input variable to assess the machinability. [25]

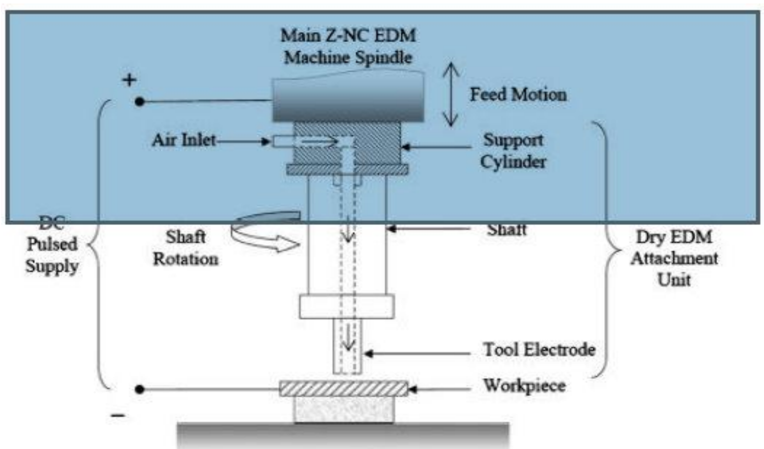


Fig.2.2: Experimental set up[25]

Material removal rate is higher with rotating tube electrode as compare to rotating solid electrode in EDM drilling. The electrode tube hole diameter affects the MRR, EWR and SR. with decrease in hole diameter, increase EWR and produced better MMR and SR. The increase the volume of percentage of SiC resulted in decrease in MMR,SR and increase in EWR. As the rotational speed of the tube electrode is increases, MMR and

EWR is higher and better SR. MMR and EWR is more for the injection flushing than the side flushing [25].

K. M. Patel, P. M. Pandey *et* al. [2009] study the feasibility of fabricating microholes in SiCp-Al composites using micro-electro-discharge machining (micro-EDM) with a rotary tube electrode. Material removal rate (MRR), electrode wear rate (EWR), and hole taper were considered as responses for the study. Machining is performed on 5 and 10 wt% SiCp-Al composites having particle size of 50µm and 150µm to evaluate machining characteristics. Pulse-on duration, pulse-off duration, sparking gap voltage, and servo-speed were used as input variables for EDM of SiCp-Al composites by varying the weight percentage of SiC-reinforced particles and the size of reinforcement. It is observed that MRR increases with pulse-on duration and servo-speed, whereas it decreases with an increase in pulse-off duration and sparking gap voltage. EWR increases with servo-speed and pulse-on duration. EWR has little variation with change in the pulse-off duration, deceases with increasing sparking gap voltage.Hole taper increases with an increase in pulse-on time and servo-speed, whereas it decreases with an increase in pulse-off duration and sparking gap voltage [26].

S Yeo, P Tan, E Aligiri *et* al. [2009] study The micromachining on the zirconium-based BMG (Zr57Nb5Cu15.4 Ni12.6Al10) machined by micromilling and micro-EDM processes. This qualitative study highlighted observable differences in roughness of the machined surfaces by both processes. They investigate the effects of micro-EDM machining conditions on surface roughness, burr formation, and tool wear, the micro-EDM technique was also used to machine the BMG using two energy(13.4 µJ and 0.9 µJ), input and three different tool electrodes(tungsten rod electrode, copper, and brass tube electrodes). It is observed that decreasing the input energy from 13.4 µJ to 0.9 µJ resulted in a 43%–51% reduction in surface roughness and a 63% reduction in burr width due to the generation of smaller craters and smaller amounts of molten material, respectively. By using tungsten rod electrode, copper, and brass tube electrodes, results showed that at the higher input energy of 13.4 µJ the electrode material melting point is more significant in influencing TWR than thermal conductivity, while at the lower input energy of 0.9 µJ, the effect of thermal conductivity on TWR was more significant than the melting point. Furthermore, given the greater influence of thermal conductivity at lower heat fluxes, it is found that tube-shaped electrodes experienced a reduction in TWR due to the enhancement of heat transport through a larger tool electrode area that was exposed to the dielectric. At the end of experiment results shows that tube-shaped electrodes were more suitable than rod-shaped electrodes for machining BMG at low input energy [27].

2.1.3. EDM with Polarity changing

B B Pradhan and B Bhattacharyya [2007] investigated the machining of straight-through microholes with the micro-EDM technique, using constant- and changing-polarity conditions, on Ti–6Al–4V superalloy by varying Ip and Ton. At the end of experiment, it is concluded that advantage of machining with changing polarity at exponentially decreasing time intervals. When the time domain reduces exponentially with each change, the frequency of polarity change increases which in turn increases the number of sparkings with the tool electrode at positive polarity, thereby reducing MRR and increasing TWR with the variation of Ip at fixed Ton of10µs. However, with variation of Ton at fixed Ip, MRR is increased and TWR is reduced, MRR is found to increase with increase in Ip; the value of MRR is lower for changing polarity than constant polarity. At lower Ton, MRR for changing polarity is much higher than that for constant polarity. TWR increases with increase in both Ip and Ton. For the increase in Ip the magnitude of TWR is higher for changing polarity than for constant polarity. OC is reduced with increase in Ip from 0.5 to 1 A, and is minimum at 1 A, but increases sharply from 1 to 2 A. OC increases with increase in Ip for changing polarity. With increase in Ton from1 to 20µs, OC decreases constantly for changing polarity but fluctuates with constant polarity [28].

2.1.4. EDM v/s AEGG

Ahmet and Ulas [2007] investigate improvability of surface integrity in terms of machining voltage, electrolyte flow rate and table feed rate parameters of AECG in

EDMed Ti6Al4V alloy. They performed Scanning electron microscopy (SEM), X-ray diffraction (XRD), energy dispersive spectrograph (EDS) and surface roughness measurement to study the surface characteristics of the machined samples. In this experiment, the EDMed surfaces are grinded by abrasive electrochemical process with different machining parameters, machining voltage, table feed rate and electrolyte flow rate. A recast white layer formed on the EDMed machined surface. The surfaces are heavily rough because of the debris which are not flashed away completely from the machining zone. The applied current does affect the surface roughness. In the AECG process, at the lower voltages, a strongly attached TiO film was found on the surface which hinders the current flow between the wheel and workpiece.With increasing voltage, this film was broken and anodic dissolution took place. Active metal dissolution starts approximately at 4V and the MRR increases sharply after this point. The effect of abrasive particles on MRR was restricted by high table feed rates. The contact of abrasives on surface decreased with feed rate and surface roughness is improved by eliminating abrasive damages. It is possible to achieve surfaces free from EDM damages by AECG. The surface roughness was improved as 92.19, 3.23 and 1.98% by machining voltage, electrolyte flow rate and table feed rate [29].

2.1.5. EDM v/s ECDM

Liu, Yue and Guo [2010] analyze the discharge mechanism in electrochemical discharge machining (ECDM) of a particulate reinforced metal matrix composite. They establish a model to reveal the electric field acting on a hydrogen bubble in ECDM process. This model is capable to predict the position of the maximum field strength on the bubble surface as well as the critical breakdown voltage for spark initiation. They performed no. of experiments to verify the model and the experimental results agreed well with the predict values.The experimental result show that with increase in current, duty cycle, pulse duration or electrolyte concentration increase the occurrence of arcing action in ECDM. The experimental result shows that in the ECDM process, the voltage waveform consists of a charging phase, then breakdown which is followed by the period of arcing, with arc maintaining voltage similar to that of an EDM discharge. The craters of ECDM and EDM are studied, the formation mechanism of craters for both processes are same, which is believed to be due to the arc effect. An Al4C3 phase was detected on the surface of the EDM specimen but not on the ECDM specimen [30].

2.2. Summary of literature review

A lot of work has been done with EDM, to study the effect of parameter on MRR, TWR & SR. The effect of parameter has been done by either simple EDM or with PMEDM. From the literature survey, it is observed that the study of effects with EDM is still at the experimental stage. Many researchers [6],[11],[14],[16],[17],[18] studied the effects on MRR, TWR & SR for machining of Al MMCs. Some researchers [29],[30] compare the EDM with other processes like AEGG, ECDM. With Reverse polarity [28] MRR is less than MRR with straight polarity and TWR is higher with reverse polarity. Some researchers [25],[26],[27], used tubular electrode for EDM. MRR is higher with Rotating tube electrode as compare to rotating solid electrode and diameter of tube electrode is also affects the MRR, TWR & SR. Many researchers [7],[9],[10],[12],[13],[15] used the hard material like tungsten carbide, die steel to machine with EDM. And investigated the various effects on the machining parameters such MRR, TWR & SR.

CHAPTER-3

DESIGN OF STUDY

3.1 Introduction

A large number of inputs process parameter can be varied in the EDM process, each having its own impact on output parameters such as Material Removal Rate (MMR), Tool Wear Rate (TWR), and Surface Roughness (SR). Various input parameters are:

a. Polarity
b. Pulse on-time
c. Pulse off-time
d. Arc Gap
e. Peak Current
f. Voltage
g. Type of Dielectric flushing
h. tool material

The effect of each of these parameters on EDM process is discussed in the literature review in detail. It is also known from the previous research works that out of the above listed parameters, four parameters(peak current, pulse on-time, tool material and polarity) are directly affect the material removal rate (MMR) and tool wear rate (TWR) in EDM. Out of these four parameters, three parameters have been investigated thoroughly in this research work. The polarity has been fixed as straight polarity (electrode negative) for all the experiments. Some other input parameters which are fixed for all experiments are given in table 3.1.

Table3.1: Fixed input process parameters

S. No.	Machining Parameter	Fixed Value
1	Open Circuit Voltage	135± 5% Volts
2	Polarity	Straight
3	Machining time	10min
4	Type of Di-electric	Kerosene
5	Pulse off-time	5μs

3.2. Design of Experiments

The experimental plan was formulated considering three variables and three levels based on the Taguchi method. The independent variables selected were peak current (I), tool (T) and Pulse on-time (Ton). The responses to be studied are SR, MRR and TWR. The input parameters and its levels are shown in Table 2. In the present investigation, a L27 orthogonal array was selected and it has 27 rows and 13 columns. Each variable and the corresponding interactions were assigned to a column defined by Taguchi method. Using Taguchi's orthogonal array, a total of 27 experiments were carried out with different combinations of input parameters (Table 3.3). The analyses of the experimental data were carried out using MINITAB 15 software, which is especially used for Design Of Experiment (DOE) applications. The experimental observations were transformed into S/N ratios for measuring the quality characteristics (Table 3.2). S/N ratio is defined as the ratio of the mean of the signal to the standard deviation of the noise. S/N ratios take into account the amount of variability in the response data and closeness of the average response to the target. The S/N ratio characteristics can be classified into three categories, viz., 'smaller-the-better', 'larger-the-better' and 'nominal-the-best' characteristic. The S/N ratios were calculated for SR and TWR using smaller-the-better characteristic:

$S/N = -10 \log [MSD]$

Where $MSD = 1/n (\Sigma y^2)$

MSD = Mean Square Deviation

$S/N = -10 \log [1/n (\Sigma y^2)]$

where y is the observed data (SR or TWR)

n is the number of observations.

The S/N ratios were calculated for MRR using larger-the-better characteristic:

$S/N = -10 \log [MSD]$

Where $MSD = 1/n (\Sigma 1/y^2)$

$S/N = -10 \log [1/n (\Sigma 1/y^2)]$

where y is the observed data (MRR)

n is the number of observations.

The objectives of the models are to minimize SR and TWR, and maximize MRR. The relative contribution of each control factor on the overall measured response is obtained by ANOVA. In multiple linear regression models, a linear combination of two or more predictor variables is used to explain the variation in a response. This model gives the relationship between predictor variables and response variable by fitting a linear equation to the observed data. Multiple linear regression models were developed to predict the SR, MRR and TWR. [23]

For smaller-the-better type, target value is zero. For larger-the-better, inverse of each large value become a small value and again target value is zero.
For this experimental work, the response characteristics have been studied as under:

1. Response name : Surface Roughness(SR)
   Response type : Lower-the-better
   Units : Ra value in microns

2. Response name : Material Removal Rate(MMR)
   Response type : Larger-the-better

3. Response name : Tool Wear Rate(TWR)
   Response type : Lower-the-better

Table3.2: Parameters and their levels

Level	Peak current, I(A)	Tool	Pulse on time, Ton (μs)
1	1	cu	10
2	2	Al	20
3	3	Br	30

Table 3.3: Standard L27 Orthogonal Array (Taguchi Design)

Exp. No.	Current	Tool	On-Time
1.	1	1	1
2.	1	1	2
3.	1	1	3
4.	1	2	1
5.	1	2	2
6.	1	2	3
7.	1	3	1
8.	1	3	2
9.	1	3	3
10.	2	1	1
11.	2	1	2
12.	2	1	3
13.	2	2	1
14.	2	2	2
15.	2	2	3
16.	2	3	1
17.	2	3	2
18.	2	3	3
19.	3	1	1
20.	3	1	2
21.	3	1	3
22.	3	2	1
23.	3	2	2
24	3	2	3
25.	3	3	1
26.	3	3	2
27	3	3	3

3.3. Taguchi Technique

DOE is a powerful analysis tool for modeling and analyzing the influence of multiple control factors on the performance output. DOE approach using Taguchi technique is devised for process optimisation and identification of optimal combination of the factors for a given response. It provides a simple, efficient and systematic approach to optimise design for performance, quality and cost. Taguchi method is a powerful tool for designing high quality systems based on orthogonal arrays. Taguchi DOE method is used to evaluate the relative contribution of process and material parameters on the response. The Taguchi approach to experimentation provides an orderly way to collect, analyze and interpret data to satisfy the objectives of the study. Taguchi technique creates a standard orthogonal array to consider the effect of several factors on the target value and defines the plan of experiments. Experiments are designed and conducted to study the parameters that affect the response. Taguchi method employs a generic signal-to-noise (S/N) ratio to quantify the present variation. These S/N ratios are meant to be used as measures of the effect of noise factors on performance characteristics. Analysis of variance (ANOVA) is used to determine the design parameters or their interactions significantly influencing the response. ANOVA is a computational technique that quantitatively estimates the relative contribution of each control factor on the overall measured response and expresses it as a percentage. [23]

3.4. Anova (Analysis of Variance)

In statistic, analysis of variance (ANOVA) is collection of statistical models and their associated procedures, in which the observed variance is partitioned into components due to different explanatory variables. The initial techniques of the analysis of variance were developed by statistician and geneticist R.A Fisher in the 1920s and 1930s and are sometimes known as Fisher'ANOVA or Fisher'analysis of variance.Due to the use of fisher F-Distribution as part of the test of statistical significance.

3.5. Experimental Set Up

EDM is a thermal erosion process in which material is removed by a series of repetitive electrical discharges between the electrode (tool) and workpiece, in the presence of a dielectric fluid. The electric sparks erode very tiny pieces of metal from the workpiece to produce the desired component shape. In this study, T-3822M electric discharge machine (EDM) manufactured by VICTORY ELECTROMECH is used to remove the material from the workpiece (figure 3.1 and 3.2). The power supply used was 415V AC and kerosene oil was used as the dielectric fluid (insulating liquid). The tool electrode (cathode) and Al Alloy workpiece (anode) were submerged in the dielectric fluid and connected to a power supply which was switched on and off automatically depending on the parameters set on the controller. The power supply generated an electrical potential between the electrode and hybrid composite workpiece. When an electric pulse was delivered from the power supply, the insulating property of the dielectric fluid was momentarily broken down. This allowed small sparks (discharges) to jump the shortest distance between the tool and workpiece. These spark occurred in huge numbers at seemingly random locations between the tool and the workpiece. Therefore, the anode and cathode surfaces were bombarded by electrons and ions and the kinetic energy of these particles was transformed into heat which induced melting and vapourisation of the surface material. Since heat from such discharges eroded minute particles of workpiece, very small discharge craters were formed on the machined surface. The Ton setting determines the duration of the spark. As the potential difference was withdrawn, the plasma channel collapsed and the process went into a pause period. The constantly circulating dielectric fluid carried away the eroded particles of material during the off cycle of the pulse and also assisted in dissipating the heat caused by the sparks. The pulse-off duration was maintained at constant value of 5 μs. After the pause period, the power was turned on again and the entire process was repeated a number of times every second and the material were removed from the workpiece in a shape complementary to that of the tool. When the spark gap was increased due to the erosion of the workpiece, the tool was automatically lowered by the machine so that the machining process can continue uninterrupted.

3.6. Measurement Procedure

Surface roughness tests conducted on all the samples. The workpiece and tool are weighed before and after the machining operation using an electronic weighing machine and the mass of the workpiece material and tool removed is calculated. The details of important test equipment used in experimental study are given below:

3.6.1. Surface roughness Tester

Surface roughness was measured using the perthometer, model SJ-400 of mitutoyo, Japan (Fig. 3.3) available in the metrology lab of Thapar University, Patiala. The equipment uses the stylus method of measurement, has profile resolution of .000.125nm and measure roughness upto 800um. A tracing length of 4.8 was used to analysis surface roughness of each sample was measured at three different positions namely, centre, left and right of each machined sample. The left and right position were taken at 6mm from centre one each side.

Figure 3.1: T-3822M electric discharge machine (EDM)

Figure 3.2: Experimental setup for EDM of Al MMCs.

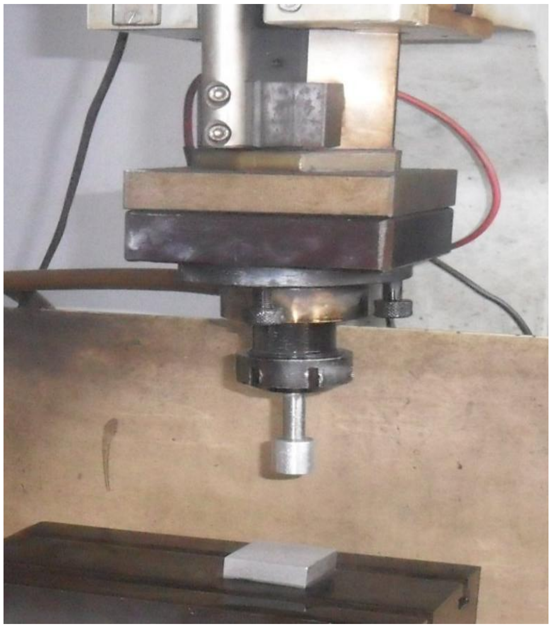


Figure 3.3: Measurement of surface Roughness using Surface roughness tester

3.6.2. X-Ray Diffraction Machine

XRD analysis of starting materials was carried out on X-Ray Diffraction machine, (model X'Pert PRO) manufactured by PANalytical, Netherland.Available in material testing lab of Punjab University, Chandigarh. The range of 2θ from the 5º to 100º was used to scan the material.

3.6.3. Scanning Electron Microscope (SEM) Machine

Microstructure was carried out of some selected samples on scanning electron Microscope, (model JSM-840A) of Joel, Japan, available in Material Testing lab of Thapar University, Patiala. The range of magnification from 10X to 3,00,000 X. SEM of samples carried out on four ranges, namely, 50X. 100X, 250X and 500X.

CHAPTER-4

RESULTS AND ANALYSIS

4.1. Introduction

This chapter includes the details of the experimental work performed on EDM machine along with the results of the experimental work. The objective of the experimentation is to study the effect of Parameters i.e Electrode material, current and On-time upon the material removal rate (MMR), tool wear rate (TWR) and surface roughness (SR) mainly using Al alloy MMCs. Also studied the effects have been studied on the Roughness of the machined surface. Signal to noise ratio was determined and graphs are generated on the basis of experimental data. The obtained results are analyzed using MINITAB 15.

4.2. Material Characterization

4.2.1. XRD (X-Ray Diffraction)

To determine the phase present Al-ZrO_2 MMC, XRD in powder form is carried out. Figure 4.1 shows the X-ray diffraction (XRD) patterns of the the Al alloy MMCs having 5% ZrO_2. The obtained peaks were matched with standard JCPDS cards of Al, Si and ZrO_2. The peaks of Al, $Al_2SiO_5$and $ZrSiO_4$ are detected. No other impurity peaks were present. Few peaks appeared for $ZrSiO_4$. This is because the concentration of ZrO2 is extremely low equal to 5% and maximum peaks shows for Al. These results indicate that the major phase of Al. Si is appeared in the form of silicate as shown in fig.

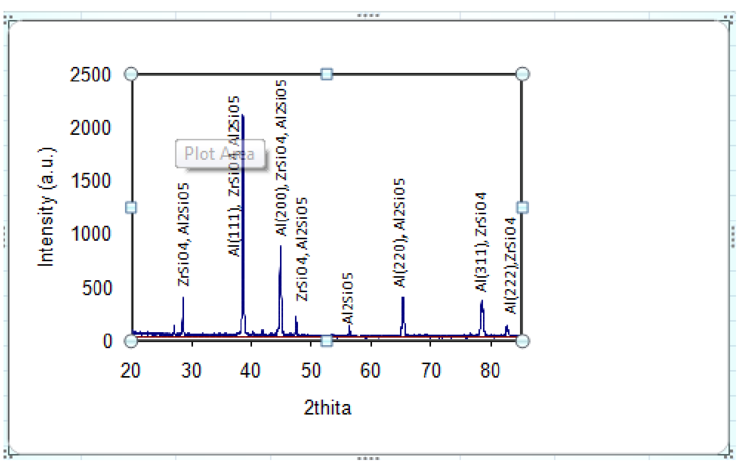
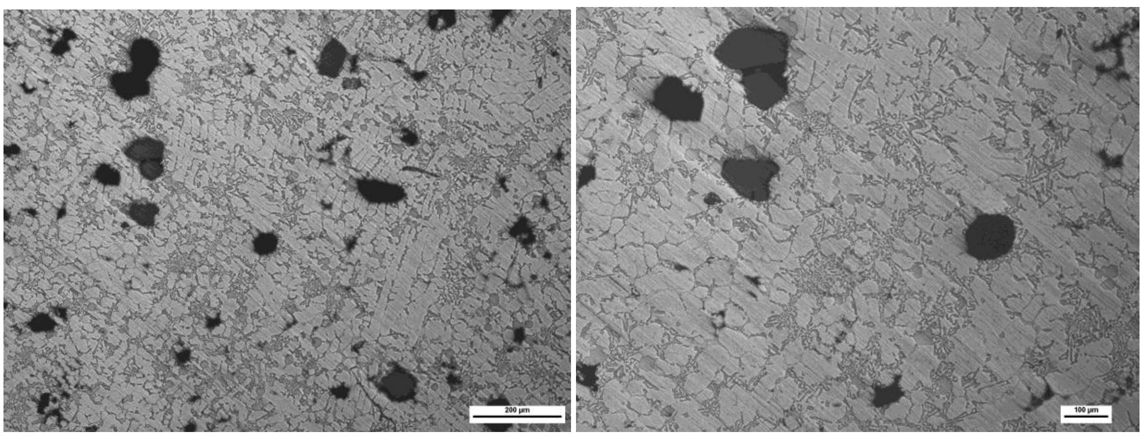


Fig. 4.1: XRD pattern of the Al MMCs

4.2.2. Metallography

The optical micrographs of Al MMCs reinforced with 5% ZrO_2 fine particles (106-125) are shown in Fig. 4.2. this figure shows fairly distribution of reinforced particles in alloy matrix .figure 4.2(b) shows the higher magnification micrograph of the Al MMCs where fragmented dendrites in the alloy matrix can be seen, though limited dendritic growth in the zircon depleted region is also visible. This growth has occurred because of clustering of zircon. Coarse size zircon are pushed or engulfed by advancing solid-liquid interface creating sufficient space inside the matrix, which leads to growth of dendrite. Fig. 4.2(a) shows the homogeneous distribution of coarse zircon in the MMCs. The smooth interface indicates good bonding between particle and alloy matrix is exhibited.



(a) (b)

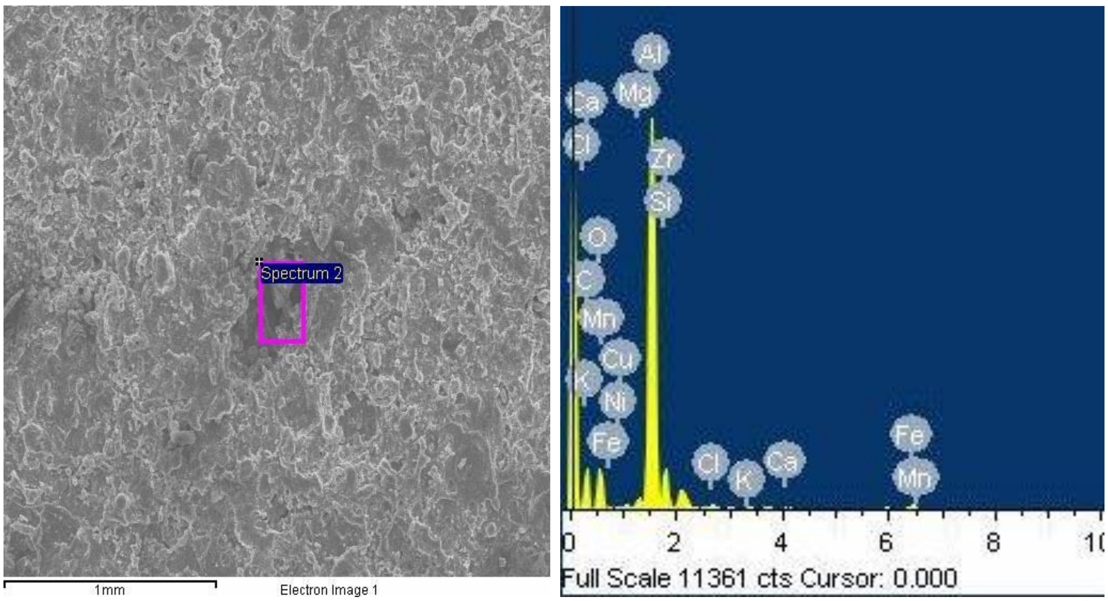
Fig. 4.2: The microstructure of the aluminium metal matrix composite having 5% ZrO_2 (a) 50X (b) 100X

4.2.2. Energy Dispersive Spectrometer (EDS)

Figure 4.3 shows the bulk EDS graph, The Al MMCs is analyzed using EDS to determine the elemental composition. Figure 4.3 summarizes the results of EDS quantitative analysis for the main alloying constituent such as Al, Cu ,Mg , Si , Ni, Fe and Zr. The composition of this Al alloy LM13+ZrO_2 is show in table 4.1.

Table 4.1: Chemical composition of Al alloy LM13+ZrO_2

Material	Al	Zr	Cu	Mg	Si	Fe	Mn	Ni
Chemical Composition(%)	77.18	4.76	1.42	1.42	12.38	0.95	0.47	1.42



4.3 EDS analysis of Al MMCs

4.3. Expermental Results:

The experiments are conducted as per the orthogonal array and the material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR) values obtained for various combinations of parameters are shown in Table 4.2. The influence of control parameters on the output has been evaluated using S/N ratio response analysis. The control factor with the greatest influence was determined by the difference between the maximum and minimum value of the mean of S/N ratios. Ranking of predominant parameters influencing the material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR) using S/N ratios obtained for different parameter levels are listed in Tables 4.7, 4.12 and 4.17. It can be observed from these tables that peak current was the most dominant parameter influencing the material removal rate (MRR), tool wear rate

(TWR). Figures 4.5, 4.7 and 4.9 show the mean of S/N ratios for MRR, TWR and SR graphically. Figures 4.4, 4.6 and 4.8 depict the main effects plot for mean MRR, TWR and SR. The analysis of the experimental results using S/N ratio gave the following optimum machining condition that result in minimum SR: tool = Al, I = 1 A, and On-Time = 10 µs (Figure 4.9). The optimal setting of control parameters for maximum MRR is Tool = Al, current = 3 A and on-time = 30 µs (Figure 4.5). The optimum machining condition for minimum TWR is Tool= Cu, I = 1 A and on-time = 20 µs (Figure 4.7).

Table 4.2: Orthogonal array and experimental results

Exp. no.	Tool	Current (amp.)	On-Time (µs)	MMR (mm^3/min)	TWR (mm^3/min)	SR (µm)
1	Brass	1	10	3.0358	0.9987	1.61
2	Brass	1	20	5.3010	1.6735	1.77
3	Brass	1	30	6.2831	1.5313	1.93
4	Brass	2	10	11.0752	2.5542	2.09
5	Brass	2	20	13.8351	3.1915	1.61
6	Brass	2	30	12.2652	3.0000	1.73
7	Brass	3	10	16.7526	3.4771	1.85
8	Brass	3	20	19.3225	4.2048	2.03
9	Brass	3	30	22.1827	4.8614	2.23
10	Cu	1	10	4.6000	0.0841	0.98
11	Cu	1	20	4.5125	0.0279	1.28
12	Cu	1	30	6.5627	0.0356	1.64
13	Cu	2	10	11.9677	0.0993	1.66
14	Cu	2	20	12.3548	0.0200	1.29
15	Cu	2	30	13.2975	0.3928	1.48
16	Cu	3	10	19.0000	0.4497	1.72
17	Cu	3	20	19.2043	0.4716	1.88
18	Cu	3	30	23.9569	0.5324	2.01
19	Al	1	10	4.4609	0.2757	0.95

20	Al	1	20	7.2365	0.8250	1.17
21	Al	1	30	7.4014	0.9464	1.89
22	Al	2	10	13.0179	0.5178	0.99
23	Al	2	20	15.1516	0.6442	1.27
24	Al	2	30	16.2211	1.0035	1.41
25	Al	3	10	20.8853	1.4714	1.12
26	Al	3	20	25.5602	2.1392	1.31
27	Al	3	30	25.7240	1.6500	1.48

4.4. Results and analysis for material removal rate (MRR)

The results for MRR for each of the 27 treatments conditions with repetition are given in the Table 4.2. MRR of each sample is calculated from weight difference of workpiece before and after the experiment, which is given by;

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

Where, W_i = Initial weight of workpiece material (gms)

W_f = Final weight of workpiece material (gms)

t = Time period of experiment in minutes

ρ = Density of workpiece in g/cm³

Table 4.3: Results for MRR

Exp. no.	Tool	Current (amp.)	On-Time (μs)	MRR (mm³/min)	S/N Ratio
1	Brass	1	10	3.0358	9.6455
2	Brass	1	20	5.3010	14.4872
3	Brass	1	30	6.2831	15.9635
4	Brass	2	10	11.0752	20.8870
5	Brass	2	20	13.8351	22.8196
6	Brass	2	30	12.2652	21.7735

7	Brass	3	10	16.7526	24.4816
8	Brass	3	20	19.3225	25.7213
9	Brass	3	30	22.1827	26.903
10	Cu	1	10	4.6000	13.2552
11	Cu	1	20	4.5125	13.0883
12	Cu	1	30	6.5627	16.3417
13	Cu	2	10	11.9677	21.5602
14	Cu	2	20	12.3548	21.8367
15	Cu	2	30	13.2975	22.4754
16	Cu	3	10	19.0000	25.5751
17	Cu	3	20	19.2043	25.6680
18	Cu	3	30	23.9569	27.5886
19	Al	1	10	4.4609	12.9884
20	Al	1	20	7.2365	17.1906
21	Al	1	30	7.4014	17.3863
22	Al	2	10	13.0179	22.2908
23	Al	2	20	15.1516	23.6092
24	Al	2	30	16.2211	24.2016
25	Al	3	10	20.8853	26.3968
26	Al	3	20	25.5602	28.1513
27	Al	3	30	25.7240	28.2068

Table 4.4: ANOVA for Means-MRR

source	DF	Seq. SS	Adj SS	Adj MS	F-test	P	P(%)
Tool	2	40.48	40.48	20.241	13.49	0.000	3.22
Current	2	1139.39	1139.39	569.696	379.80	0.000	90.60
On-Time	2	47.77	47.77	23.885	15.92	0.000	3.8
Residual Error	20	30	30	1.500			2.38
Total	26	1257.64					100

4.4.1. Influence of Parameters on MRR

MRR is increase in an almost linear fashion with increase in peak current at all Ton values and with different electrodes (Figure 4.4). An increase in peak current produced stronger sparks which heated the workpiece to a very high temperature, thereby enhancing the erosion and MRR of the metal matrix composites. MRR is also increase with an increase in On-Time at all peak current and with different electrodes. Generally, low frequency and high power combination results in higher crater volumes and MRR. Due to the increase in Ton, there is a reduction in the frequency and an increase in the spark energy which increased the MRR. MRR is different for different material electrodes, MRR is minimum for Brass, maximum for Al and MRR for Copper is lying in between MRR of Brass and Copper.

Table 4.5: Response table for means – MRR

Level	Tool	Current	On-Time
1	12.228	5.488	11.644
2	12.828	13.243	13.609
3	15.073	21.399	14.877
Delta	2.845	15.911	3.233
Rank	3	1	2

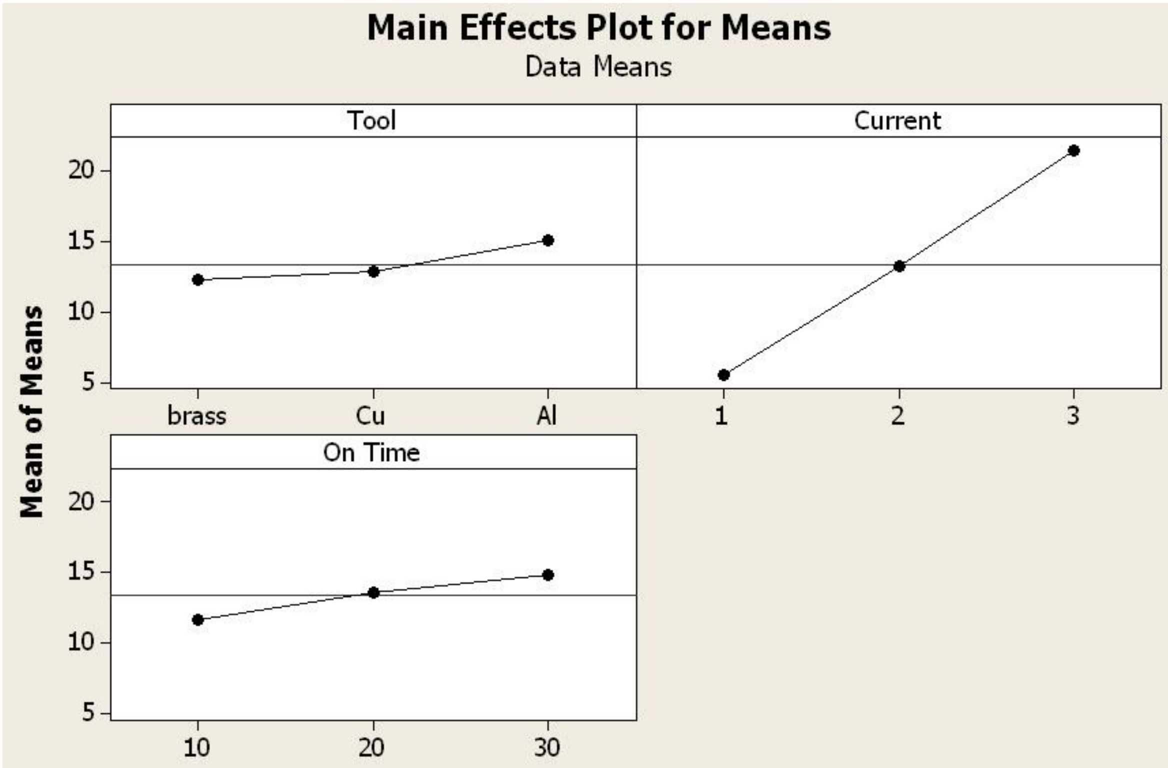


Figure 4.4: Main effects plot for Means-MRR

Table 4.6: ANOVA for S/N ratios-MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P (%)
Tool	2	18.74	18.74	9.369	8.83	0.002	2.5
Current	2	673.59	673.59	336.793	317.34	0.000	90.30
On-Time	2	32.37	32.37	16.185	15.25	0.000	4.34
Residual Error	20	21.23	21.23	1.061			2.86
Total	26	745.92					100
S = 1.225			R-Sq = 97.6%		R-Sq (adj) = 96.9%		

4.3.2. Model Analysis of MRR

The coefficients of model for S/N ratios for MRR are shown in Table 4.6. The parameter R^2 describes the amount of variation observed in MRR is explained by the input factor. R^2 is equal to 97.6% indicate that the model is able to predict the response with high accuracy. Adjust R^2 is a modified R^2 that has been adjusted for the number of terms in the model. If unnecessary terms are included in the model, R^2 artificially high, but adjusted R^2 is equal to 96.9% may get smaller. The standard deviation of errors in the modeling, S= 1.225. Comparing the P-value to a commonly used α-level = 0.05, it is found that if the P-value is less than or equal to α, it can be concluded that the effect is significant, otherwise it is not significant.

Table 4.7: Response table for S/N ratios – MRR

Level	Tool	Current	On-Time
1	20.30	14.48	19.68
2	20.82	22.38	21.40
3	22.27	26.52	22.32
Delta	1.97	12.04	2.64
Rank	3	1	2

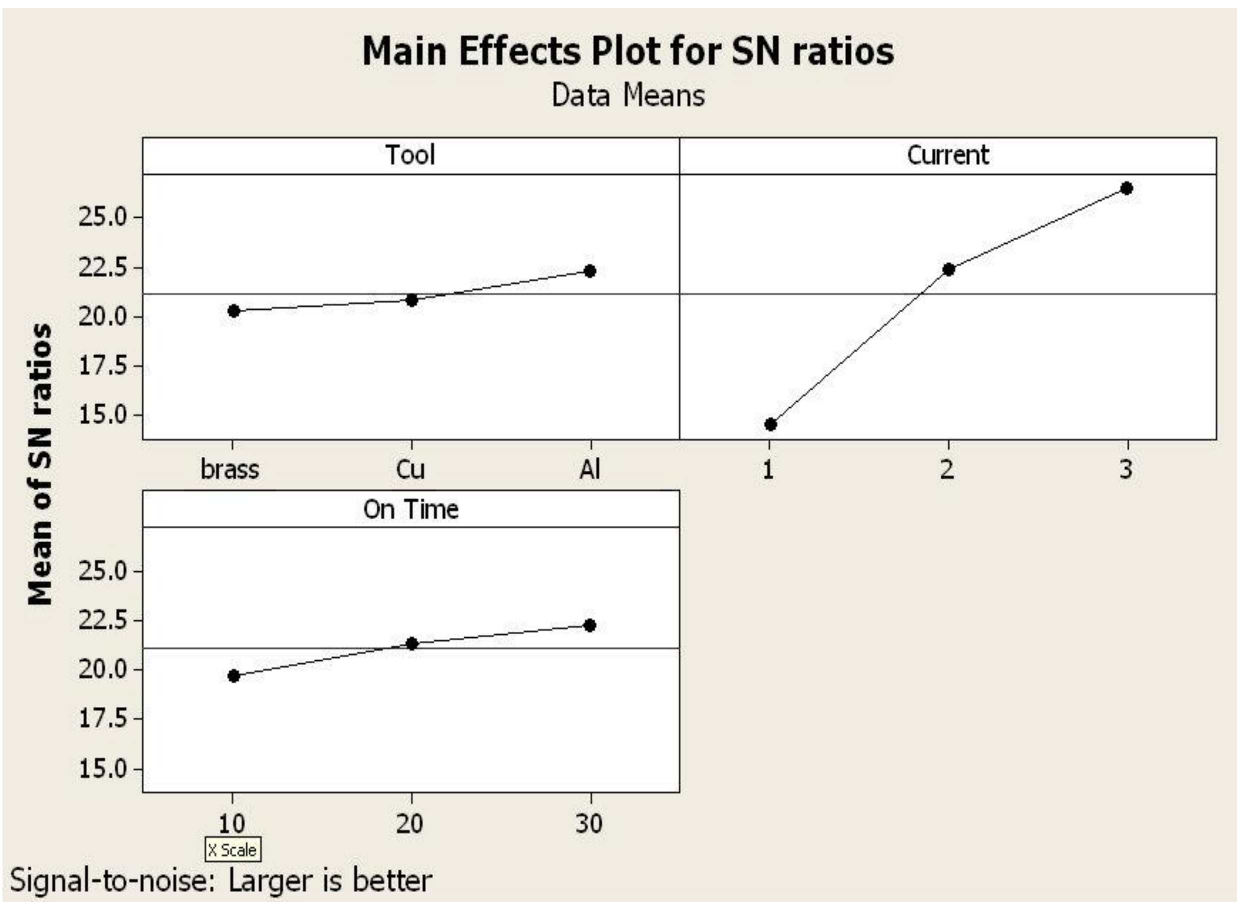


Figure 4.5: Mean of S/N ratios for MRR

4.5. Results and analysis for tool wear rate (TWR)

The results for TWR for each of 27 treatments conditions with repetition are given in table 4.8. TWR of each sample is calculated from weight difference of Tool before and after the experiment, which is given by;

TWR = $\{(W_i - W_f)/\rho \times t\} \times 1000$ mm³/min

Where, W_i = Initial weight of Tool (gms)

W_f = Final weight of Tool (gms)

t = Time period of experiment in minutes

ρ = Density of Tool in g/cm³

Table 4.8: Results for TWR

Exp. no.	Tool	Current (amp.)	On-Time (μs)	TWR (mm³/min)	S/N Ratio
1	Cu	1	10	0.0841	14.6989
2	Cu	1	20	0.0279	31.0879
3	Cu	1	30	0.0356	36.1236
4	Cu	2	10	0.0993	20.0584
5	Cu	2	20	0.0200	33.9794
6	Cu	2	30	0.3928	8.1166
7	Cu	3	10	0.4497	6.9415
8	Cu	3	20	0.4716	6.5276
9	Cu	3	30	0.5324	5.4752
10	Al	1	10	0.2757	11.1913
11	Al	1	20	0.8250	1.6709
12	Al	1	30	0.9464	0.4785
13	Al	2	10	0.5178	5.7168
14	Al	2	20	0.6442	3.8196
15	Al	2	30	1.0035	-0.0303

16	Al	3	10	1.4714	-3.3546
17	Al	3	20	2.1392	-6.6050
18	Al	3	30	1.6500	-4.3497
19	Brass	1	10	0.9987	0.0113
20	Brass	1	20	1.6735	-4.4725
21	Brass	1	30	1.5313	-3.7012
22	Brass	2	10	2.5542	-8.1451
23	Brass	2	20	3.1915	-10.0799
24	Brass	2	30	3.0000	-9.5424
25	Brass	3	10	3.4771	-10.8243
26	Brass	3	20	4.2048	-12.4749
27	Brass	3	30	4.8614	-13.7352

Table 4.9: ANOVA for Means-TWR

Source	DF	Seq. SS	Adj SS	Adj MS	F-test	P	P(%)
Tool	2	31.5724	31.5724	15.7862	52.00	0.000	66
Current	2	9.2276	9.2276	4.6138	15.20	0.000	19.3
On-Time	2	0.9571	0.9571	0.4785	1.58	0.231	2
Residual Error	20	6.0720	6.0720	.3036			12.7
Total	26	47.8290					100

4.5.1. Influence of Parameters on TWR

The analysis of variances for the factors are tool, current and on-time shown in the table 4.9 is clearly indicate that the on-time is not important for influencing TWR and the value of current and electrode material is most effected the TWR. During the process of EDM, the influences of various machining parameters like current. Tool material and on-time has significant effect on TWR as shown in main effect plot for means of TWR in figure 4.6. Increasing the current in the range 1 to 3A the TWR is increasing because of current increases the pulse energy and thus more heat energy is produced in the tool and workpiece interface, leads to increase the melting and evaporation of the electrode, the current is directly proportional to TWR and on-time has no significant effect on TWR, very little variation in TWR, as increase the on-time TWR is slightly increase. And tool material has significant effect on TWR. Very small TWR for copper but for Brass material, TWR is drastically increase and when Al material is used, TWR is lies in between Copper and Brass

Table 4.10: Response table for means – TWR

Level	Tool	Current	On-Time
1	0.2437	0.7198	1.1142
2	1.0526	1.2693	1.4664
3	2.8325	2.1397	1.5482
Delta	2.5888	1.4199	0.4339
Rank	1	2	3

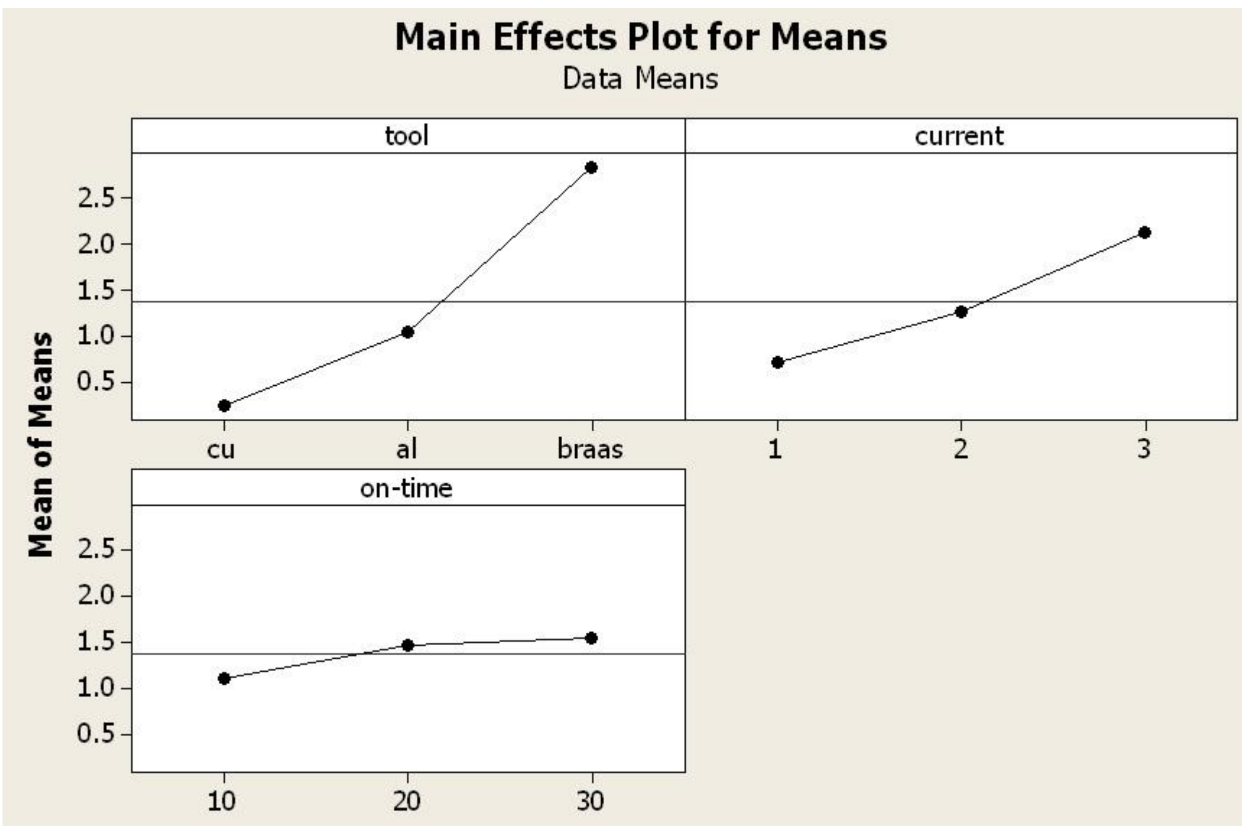


Figure 4.6: Main effects plot for Means-TWR

Table 4.11: ANOVA for S/N ratios-TWR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P (%)
Tool	2	3192.13	3192.13	1596.07	38.31	0.000	65.5
Current	2	813.47	813.47	406.74	9.76	0.001	16.7
On-Time	2	35.63	35.63	17.82	0.43	0.658	0.7
Residual Error	20	833.33	833.33	41.67			17.1
Total	26	4874.57					100
S = 0.5510 R-Sq = 87.3% R-Sq (adj) = 83.5%							

4.5.2. Model Analysis of TWR

The coefficients of model for S/N ratios for TWR are shown in Table 4.11. The parameter R^2 describes the amount of variation observed in TWR is explained by the input factor. R^2 is equal to 87.3% indicate that the model is able to predict the response with high accuracy. Adjust R^2 is a modified R^2 that has been adjusted for the number of terms in the model. If unnecessary terms are included in the model, R^2 artificially high, but adjusted R^2 is equal to 83.5% may get smaller. The standard deviation of errors in the modeling, S=0.5510. Comparing the P-value to a commonly used α-level = 0.05, it is found that if the P-value is less than or equal to α, it can be concluded that the effect is significant, otherwise it is not significant

Table 4.12: Response table for S/N ratios – TWR

Level	Tool	Current	On-Time
1	18.1121	9.6765	4.0327
2	0.9486	4.8770	4.8281
3	-8.1071	-3.5999	2.0928
Delta	26.2193	13.2765	2.7353
Rank	1	2	3

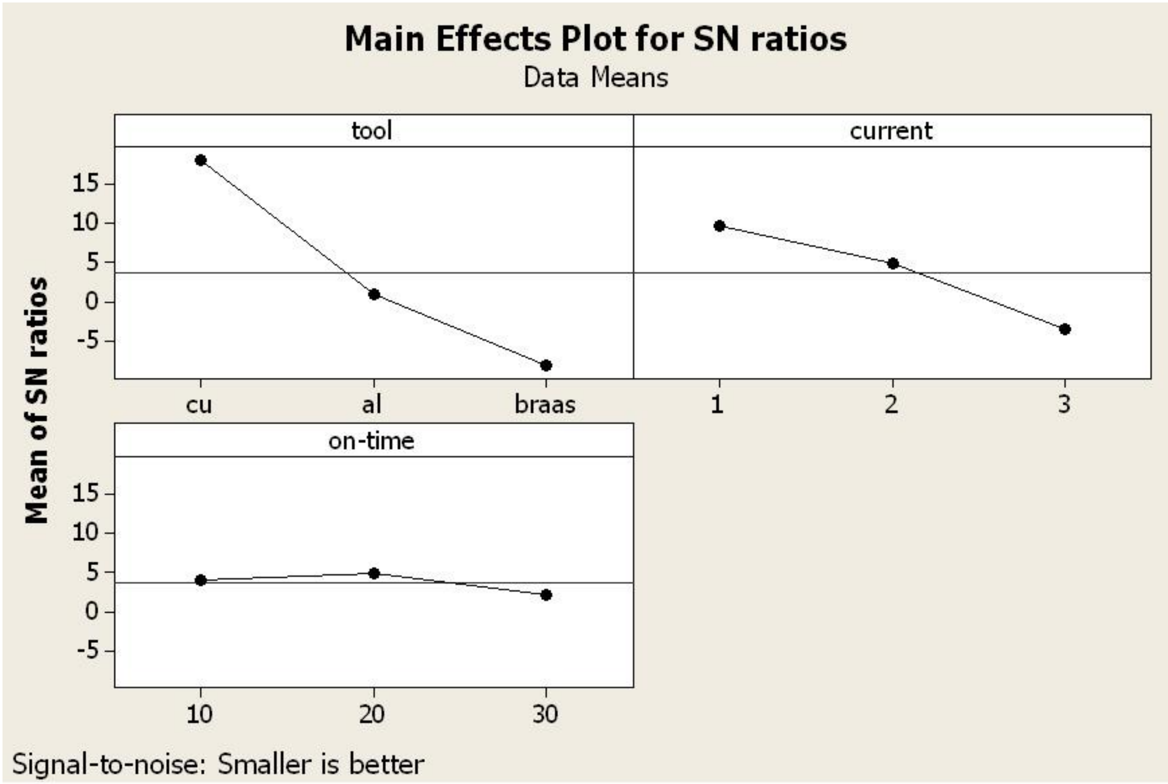


Figure 4.7: Mean of S/N ratios for TWR

4.5. Results and analysis for Surface roughness (SR)

The results for SR for each of 27 treatments conditions with repetition are given in table 4.13. SR of each sample is measured with the help of surface roughness tester.

Table 4.13: Results for SR

Exp. no.	Tool	Current (amp.)	On-Time (µs)	SR (µm)	S/N Ratio
1	Al	1	10	0.95	0.44553
2	Al	1	20	1.17	-1.36372
3	Al	1	30	1.89	-5.52924
4	Al	2	10	0.99	0.08730
5	Al	2	20	1.27	-2.07607
6	Al	2	30	1.41	-2.98438
7	Al	3	10	1.12	-0.98436
8	Al	3	20	1.31	-2.34543

9	Al	3	30	1.48	-3.40523
10	Cu	1	10	0.98	0.81917
11	Cu	1	20	1.28	-2.14420
12	Cu	1	30	1.64	-4.29688
13	Cu	2	10	1.66	-4.40216
14	Cu	2	20	1.29	-2.21179
15	Cu	2	30	1.48	-3.40523
16	Cu	3	10	1.72	-4.71057
17	Cu	3	20	1.88	-5.48316
18	Cu	3	30	2.01	-6.06392
19	Brass	1	10	1.61	-4.13652
20	Brass	1	20	1.77	-4.95947
21	Brass	1	30	1.93	-5.71115
22	Brass	2	10	2.09	-6.40293
23	Brass	2	20	1.61	-4.13652
24	Brass	2	30	1.73	-4.76092
25	Brass	3	10	1.85	-5.34343
26	Brass	3	20	2.03	-6.14992
27	Brass	3	30	2.23	-6.96610

Table 4.14: Anova for means-SR

Source	**DF**	**Seq. SS**	**Adj SS**	**Adj MS**	**F-test**	**P**	**P(%)**
Tool	2	1.9340	1.9340	0.96698	78.31	0.000	55.52
Current	2	0.5624	0.5624	0.28120	22.77	0.000	16.13
On-Time	2	0.7403	0.7403	0.37014	29.98	0.000	21.25
Residual Error	20	0.2470	1.2470	0.01235			7.1
Total	26	3.4836					100

4.6.1. Influence of Parameters on SR

From the main effects plot (Figure 4.8), it can be observed that the SR of the machined MMCs surface increases when peak current and on-time are increased and Surface roughness is minimum for Al maximum for Brass. The electric-discharge machined surface consists of a multitude of overlapping craters that are formed by spark discharges. The size of these craters depends on the discharge energy and pulse duration. The increase in peak current increases the discharge energy and spark intensity which promoted melting and vaporization of the composite material. Thus, much larger and deeper craters are generated on the MMCs surface contributing to higher SR. It is a well known fact that spark energy increases with Ton. Therefore, when the Ton was increased, greater volume of material was removed per spark and hence much deeper craters were created on the machined surface leading to higher SR values. As shown in figure 4.8. SR is minimum with Al tool and maximum with Brass tool and surface roughness for copper tool is in middle. And surface roughness is also analysis with SEM and it is observed that SR is minimum with Al tool and maximum with Brass tool.

Table 4.15: Response table for means-SR

Level	Tool	Current	On-Time
1	1.217	1.39	1.339
2	1.541	1.503	1.547
3	1.872	1.737	1.744
Delta	0.656	0.347	0.406
Rank	1	3	2

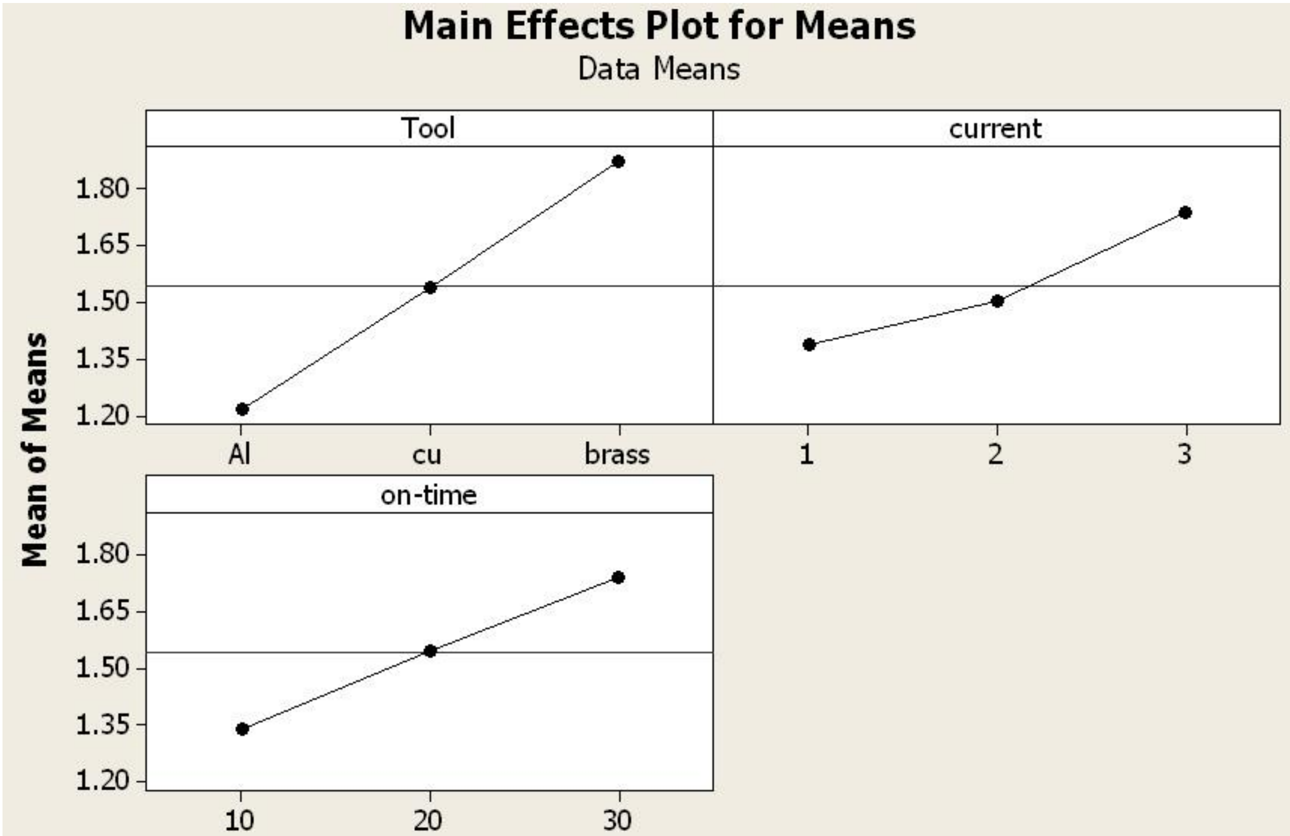


Figure 4.8: Main effects plot for Means- SR

Table 4.16; ANOVA for S/N ratios-SR

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P (%)
Tool	2	64.24	64.24	32.1197	56.83	0.000	53
Current	2	18.65	18.65	9.3271	16.50	0.000	15.38
On-Time	2	27.06	27.06	13.5294	23.94	0.000	22.32
Residual Error	20	11.30	11.30	0.5652			9.3
Total	26	121.26					100
S = 0.7518 R-Sq = 90.7% R-Sq (adj) = 87.9%							

4.6.2. Model Analysis of SR

The coefficients of model for S/N ratios for SR are shown in Table 4.16. The parameter R^2 describes the amount of variation observed in SR is explained by the input factor. R^2 is equal to 90.7% indicate that the model is able to predict the response with high accuracy. Adjust R^2 is a modified R^2 that has been adjusted for the number of terms in the model. If unnecessary terms are included in the model, R^2 artificially high, but adjusted R^2 is equal to 87.9% may get smaller. The standard deviation of errors in the modeling, S=0.7518. Comparing the P-value to a commonly used α-level = 0.05, it is found that if the P-value is less than or equal to α, it can be concluded that the effect is significant, otherwise it is not significant

Table 4.17: Response table for S/N ratios-SR

Level	Tool	Current	On-Time
1	-1.618	-2.587	-2.241
2	-3.544	-3.366	-3.632
3	-5.396	-4.606	-4.686
Delta	3.378	2.019	2.444
Rank	1	3	2

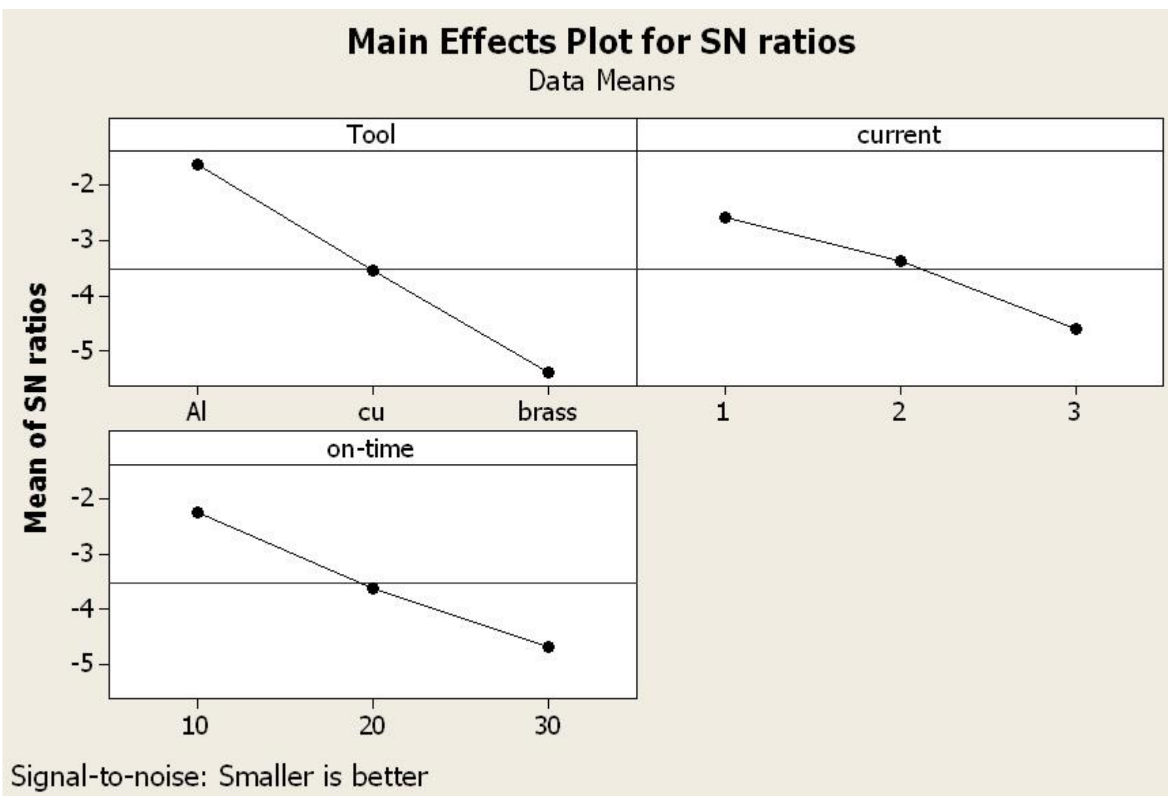


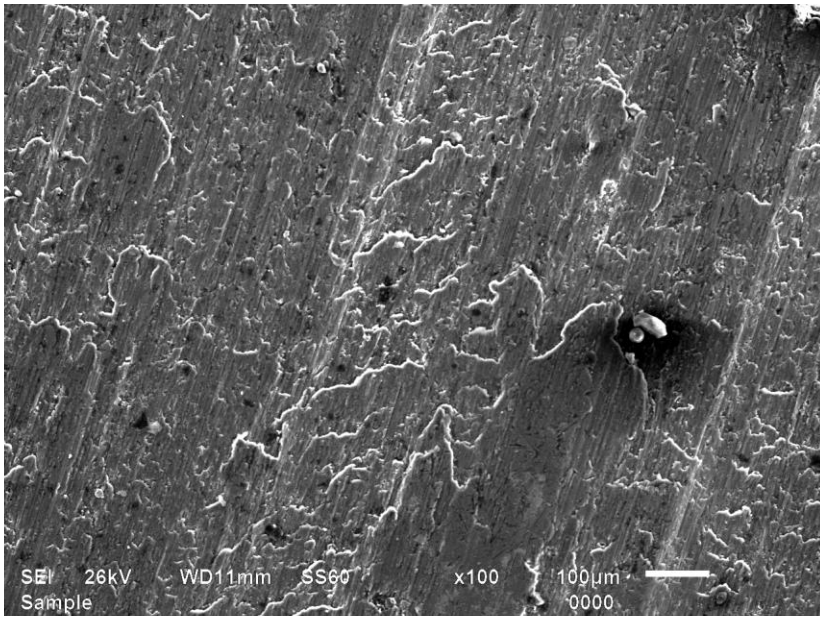
Figure 4.9: Mean of S/N ratios for SR

4.7. MICROSTRUCTURE ANALYSIS

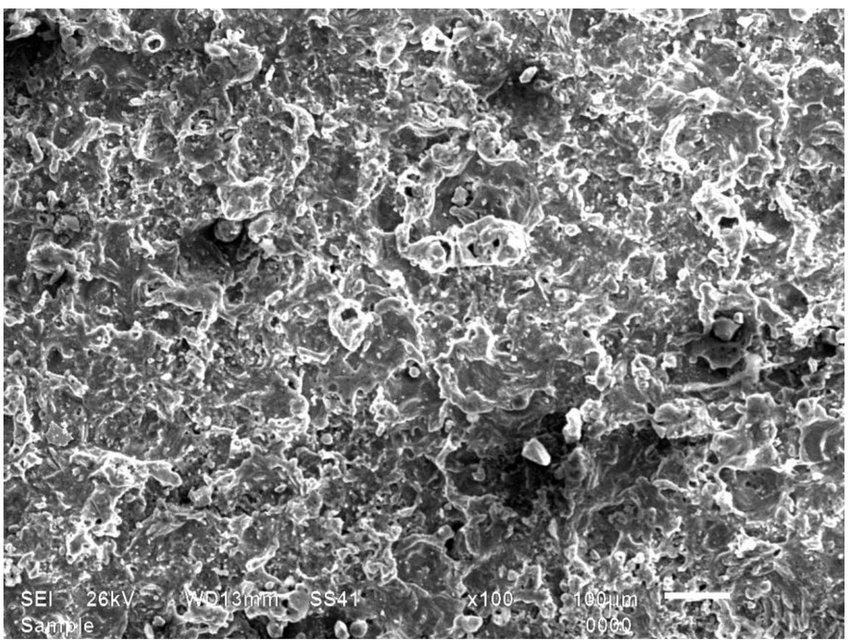
Microstructure analysis is carried out on some selected samples using scanning electron microscope to study the change in the microstructure after maching. The samples are prepared as per standard before SEM analysis on four different magnifications, namely, 50X, 100X, 250X, 500X.

Typical SEM machined surface micrographs are shown in Fig. 4.9 (b,c,d). The discharge craters are deeper when the peak current is set at 3Amp. Machined SR increased with peak current and pulse duration and SR roughness is depending upon material of electrode. SR is maximum for Brass electrode and minimum for Al electrode. The machined surface revealed that discharge craters with various diameters attributed to thermal erosions in terms of melting and vaporization, and impulsive force resulting from bursting dielectric fluid also contributed to melted material ejection, yielding discharge craters on the machined surface. Discharge craters and micropores exhibited on the machined surface deteriorate surface integrity. Moreover, the MRR increased with peak current and pulse duration and MRR is also affected by tool material. So discharge craters on the machined surface are deeper and larger because of more removed material. Surface integrity was therefore degraded with peak current, tool material and pulse duration, and SR was degraded and reached a high value. [12].

Fig. 4.9 shows the SEM photographs and surface roughness of the EDM surface for different tool material. Fig. 4.9 demonstrates that the surfaces have a complex appearance covered by craters, spherical particles and melted drops. The spherical particles are molten metals that are expelled randomly during the discharge and then solidified and attached to the surface. Change in tool material leaded to noticeable surface roughness of specimens, as shown in Fig. 4.9. Higher pulse currents cause deeper and wider craters on surface. Therefore, the surface morphology of EDM material with low currents is much flatter. [24]

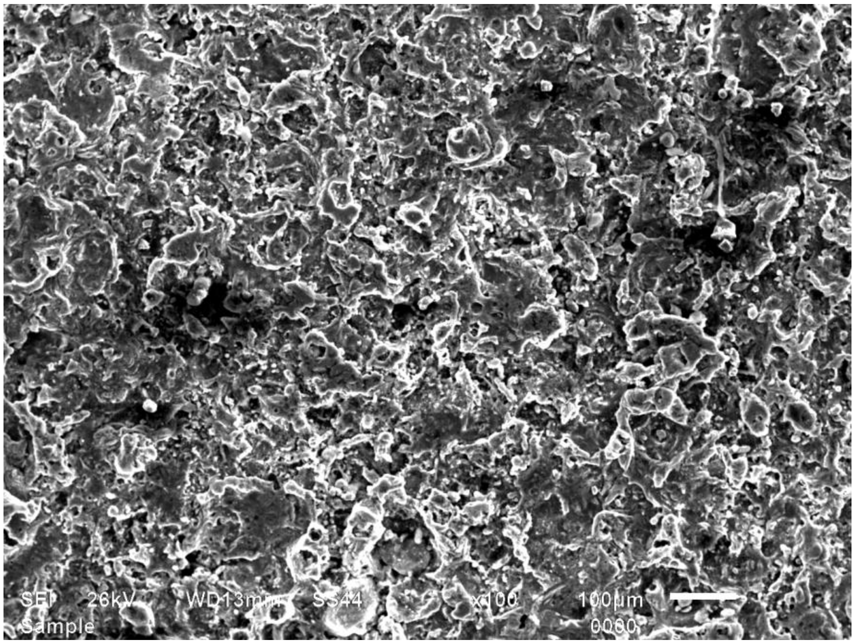


4.9(a) SEM micrograph at 100X of Al MMCs before machining. (SR = 0.81µm)



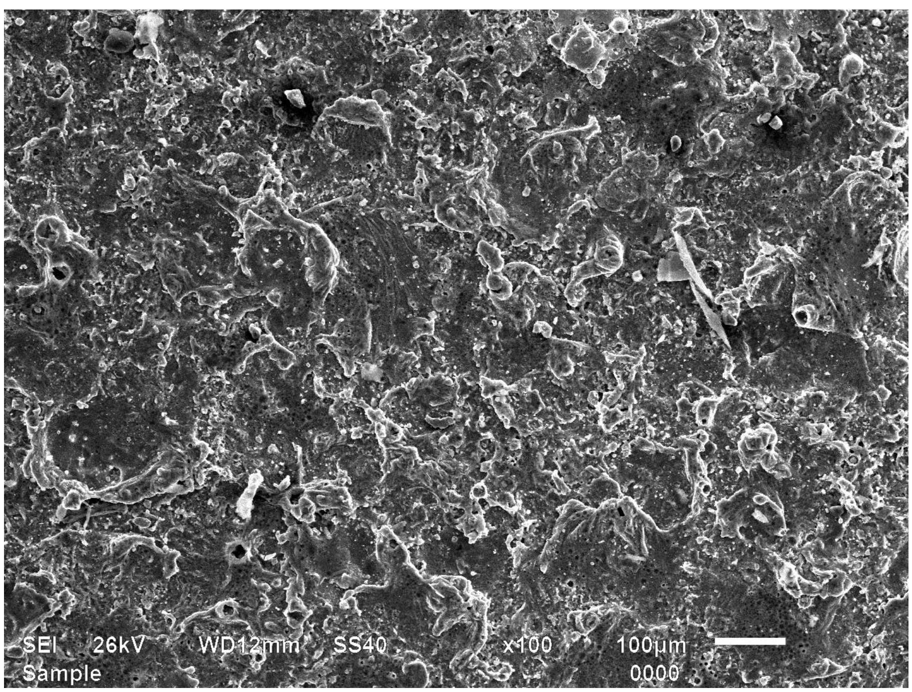
4.9 (b) SEM micrograph at 100X of Al MMCs machined with Al electrode

(SR= 1.48 µm, current 3Amp. on-time 30 µs)



4.9 (c) SEM micrograph at 100X of Al MMCs machined with Cu electrode

(SR = 2.01 µm, current 3Amp., on-time 30 µs)



4.9 (d) SEM micrograph at 100X of Al MMCs machined with Brass electrctdode

(SR = 2.23 µm, current 3Amp., on-time 30 µs)

CHAPTER-5

CONCLUSIONS

The effects of parameters i.e, Tool material, current and on-time are evaluated using Taguchi Orthogonal L27 array design. The important results obtained from analysis are concluded below:

Current is the most significant factor has highest F value (317.34) and its contribution to MRR is 92.94% followed by pulse on-time (F value 15.25) and tool material (F value 8.83) are the factor that significantly affected the MRR which had contribution to MRR is 4.46% and 2.6% respectively. For S/N ratios pulse on-time and current are significant to MRR for reducing the variation. The best results for MRR is achieve when workpiece is machined at pulse on-time 30μs, current 3 Amp with Al Electrode. The value of MRR at these parameter is 28.2068 mm^3/min.

Tool material is the most significant factor has highest F value (38.31) and its contribution to TWR is 79% followed by pulse on-time (F value 0.43) and current (F value 9.76) are the factor that significantly affected the TWR which had contribution to TWR is 0.9% and 20.1% respectively. For S/N ratios Tool material and current are significant to TWR for reducing the variation. The best results for TWR is achieve when workpiece is machined at pulse on-time 20μs, current 1 Amp with Copper Electrode The value of TWR at these parameter is 0.0279 mm^3/min.

Tool Material is the most significant factor has highest F value (56.83) and its contribution to SR is 58.4% followed by pulse on-time (F value 23.94) and current (F value 16.50) are the factor that significantly affected the SR which had contribution to SR is 24.6% and 17% respectively. For S/N ratios Tool material and pulse on-time are significant to SR for reducing the variation. The best results for SR is achieve when workpiece is machined at pulse on-time 10µs, current 1 Amp with Aluminium Electrode The value of SR at these parameter is 0.95µm.

The above conclusion can be summarized in the following points.

- Finding the result MRR, discharge current is the most influencing factor and then on-time and last is tool material. MRR is increase with the discharge current but very small effect on MRR with change in tool material.
- In the case of TWR, the most important factor is tool material. Then current and very small effect of on-time. Very small TWR for copper electrode and highest TWR for Brass electrode.
- Surface Roughness is mainly affected by Tool material and peak current. At higher value of current cause the more surface roughness and surface roughness is also higher when brass is used as tool material.

5.1. Scope of future Work

- Some parameters like polarity, off-time were kept constant, these can be varied and their effect studied. For this particular experimental setup, workpiece kept positive, whereas tool act as cathode (negative) i.e. straight polarity has been used.
- The process can be repeated by powder mixing in dielectric fluid. In this experimental set up, simple kerosene oil is used as dielectric fluid. Powders like graphite, aluminium, silicon etc are available. For future work these powders can be used.

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