A

REPORT

ON

STUDIES ON ELECTRIC DISCHARGE MACHINING OF METAL MATRIX COMPOSITES

Submitted in partial fulfilment of the Requirements for the award of the degree of

MASTER OF TECHNOLOGY
in
MECHANICAL ENGINEERING

(With Specialization in Production & Industrial Systems Engineering)

By

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KAMALJIT SINGH

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CANDIDATE'S DECLARATION

I hereby declare that the work carried out in this seminar report entitled, **"STUDIES ON ELECTRIC DISCHARGE MACHINING OF METAL MATRIX COMPOSITES",** is presented on behalf of partial fulfilment of the requirements for the award of degree of "Master of Technology" in Mechanical Engineering with specialization in Production & Industrial System engineering submitted to the Department of Mechanical and Industrial Engineering, Indian Institute of Technology, Roorkee, under the guidance of **Dr. INDERDEEP SINGH and Dr. AKSHAY DVIVEDI**, Department in Department of Mechanical and Industrial Engineering. I have not submitted the record embodied in this report for the award of any other degree or diploma.

Kamaljit Singh

Date: 25 May, 2015 **(KAMALJIT SINGH)**

Place: Roorkee

CERTIFICATE

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

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ABSTRACT

Metal Matrix Composites (MMC's) are playing a very important role in the industrial growth because of their superior properties such as high toughness, high specific strength, high temperature resistance, high stiffness etc. The superior properties of these materials cause the difficulty in their machining. In order to achieve an economic machining of MMC's and other hard to cut material (Inconel, titanium, tool steel, etc.), non conventional machining is the best alternative. This report explains the machining of MMC's with a newly developed process know as Electrical Discharge Sawing (EDS).

Electric discharge sawing is similar to conventional EDM process, but extra reciprocating motion is given to the tool which enhances the flushing efficiency of the process which ultimately yields high MRR. Scotch yoke mechanism is used to generate reciprocating motion.

There still exist numerous difficulties in cutting advanced materials, super alloys and metal matrix composite materials. EDS is a competent sawing process for cutting difficult to cut materials. A modified setup has been designed and developed. The sawing process has been investigated with the developed setup. The EDS setup has been developed in a Machine tool lab in MIED at IIT Roorkee.

Experimental studies have been conducted on MMC with input parameters as current, pulse on time, pulse off time, gap voltage, lift, stroke length and RPM, keeping other parameter constant. Material removal rate and tool wear rate of developed EDS process has been evaluated through standard test procedures. It has been found that the EDS process is quick as compared to the conventional cutting process.

These days there is massive demand of MMC shaft's in automobile industry. EDS may be an effective way to cut keyways and other operation in MMC shafts.

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CHAPTER 1 INTRODUCTION

No longer is EDM a "non conventional" machining methodology. It's claimed that EDM is currently the fourth most preferred machining methodology. The primary three are milling, turning, and grinding. One of the foremost reasons for the turnaround is today's EDM machines have dramatically hyperbolic their cutting speeds.

In today's extremely competitive world, it's essential to know the discharge machining (EDM) processes. Each manufacturer or analysis scholar operating during this space must learn and perceive 3 basic EDM processes: wire EDM, ram EDM and small scale hole EDM drilling.

The idea of EDM derived as such, a lot back as within the year 1770 once English chemist Joseph Priestly discovered the erosive results of electrical discharges or sparks. However, it fully was entirely in 1943 at the national capital University, wherever Lazarenko and Lazarenko exploited the harmful properties of electrical discharges for constructive use. They developed a controlled methodology of machining difficult-to-machine metals by vaporizing material from the surface of metal. The Lazarenko EDM system used resistance–capacitance reasonably power offer, that was wide used at the EDM machine at intervals the Fifties and later served because the model for ordered development in EDM.

In the earlier days of EDM discovery a typical EDM machine cuts 2 sq. inches an hour, nowadays they're rated to chop twenty times quicker and manufacturing sub micrometer finishes. For several applications, EDM is a particularly value effective machining operation.

The first EDM machines, notably ram EDM, were simple; however, with the appearance of CAD/CAM (computer aided design/computer aided machining), another revolution came processed programs can be downloaded into a machine and therefore the operation proceed mechanically. The utilization of those machines drastically enhanced productivity. With the addition of high speed computers these machines achieved quicker processing times.

Then formal logic was introduced, each for wire EDM and ram EDM. In contrast to bi level logic, that states that a statement is either true or false, formal logic permits an announcement to be partially true or false. Machines equipped with the fuzzy logic "think" and respond quickly to minute variances in machining conditions. They'll then lower or increase the ability setting as per the signal received.

Some EDM machines come back equipped with linear drives rather than rotary drives with a motor and ball screws. A motor and ball screw should take rotary action and convert it to linear motion. Linear motion or flat motors move during a straight motion therefore no conversion is needed.

Another innovation includes automatic tool changers, robots, workpiece and pallet changers, high speed finishing, and computer science that permits machines to perform several complicated machining sequences.

One in every of the superb options of the EDM method is that the speed and accuracy which will be maintained in step with the will of the operator. One in every of the largest difficulties within the machining trade is deciding needed part accuracies. Certain work items needs very close tolerances square measure typically extra and add substantial prices to the machining processes. Understanding tolerances square measure a crucial quality by reducing machining prices.

This report provides a review of the assorted analysis activities distributed within the past decade involving the EDM (Die-Sinking) method. Though the technique of fabric erosion utilized in EDM remains debaTable, the wide accepted principle of supported thermal conductivity is conferred as a process summary alongside the applications [1].

The core of the report identifies the main EDM tutorial analysis space with the headings of EDM performance measures, EDM operational parameters in conjunction with conductor style and manufacture. The ultimate parts of the report discuss these topics and suggest future direction for the EDM.

CHAPTER 2 EDM PROCESS MECHANISM,VARIENTS AND APPLICATIONS

2.1 Mechanism

The power supply provides electrical current to the electrode and the work piece. (A positive or negative charge is applied, depending upon the desired cutting conditions.) The gap between the electrode and the work piece is surrounded with dielectric oil. The oil acts as an insulator which allows sufficient current to develop.

The material erosion mechanism primarily makes use of electricity and turns it into thermal energy through a series of distinct electrical discharges occurring between the conductor and workpiece immersed in an exceedingly dielectric fluid as shown in Figure 1 [2].

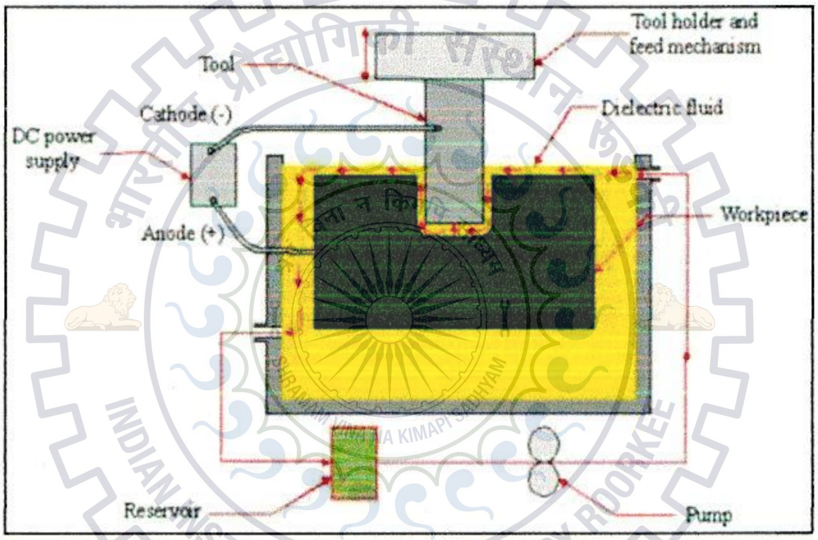


Figure 1: Schematic diagram of EDM mechanism [2]

Once sufficient electricity is applied to the electrode and the work piece, the insulating properties of the dielectric oil as shown in Figure 2. A plasma zone is quickly formed which reaches up to 8000° to 12000°C. The heat causes the fluid to ionize and allows sparks of sufficient intensity to melt and vaporize the material. This takes place during the controlled "on time" phase of the power supply.

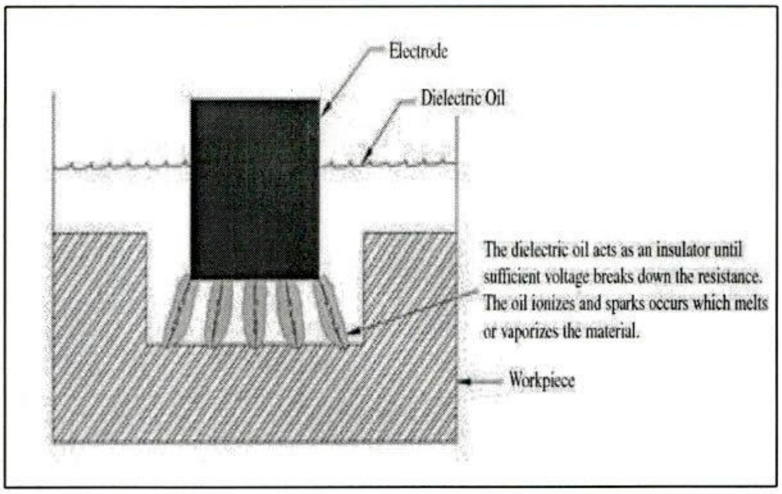


Figure 2: Spark causes the material to melt and vaporize [2]

During the pulse off times, the dielectric oil cools the vaporized material while the pressurized oil removes the EDM debris as shown in Figure 3. The amount of electricity during the pulse on time determines the depth of the workpiece erosion.

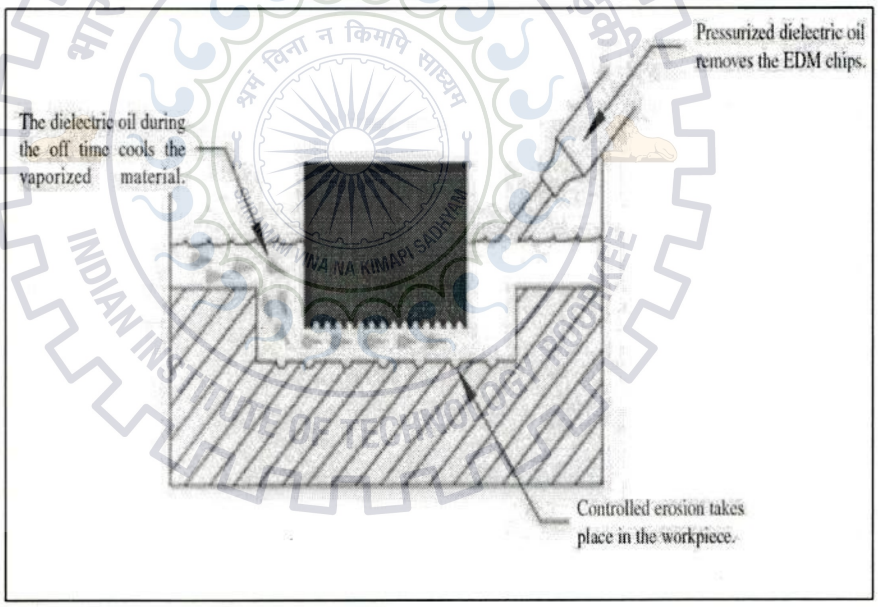


Figure 3: Pressurized dielectric oil removes the EDM chips [2]

Polarity

Polarity refers to the direction of the current flow in relation to the electrode. The polarity can be either positive or negative. (Polarity changes are not used in wire EDM.) Changing the polarity can have dramatic effects when we do ram EDM machining. Generally, electrodes with positive polarity wear better, while electrodes with negative polarity cut faster.

However, some metals do not respond this way. Carbide, titanium, and copper are generally cur with negative polarity.

No - wear

An electrode that wears less than 1% is considered to be in the no – wear cycle. No – wear is achieved when the graphite electrode is in positive polarity and pulse on time are long and pulse off time are short. During the times of no – wear, the electrode will appear silvery showing that the work piece is actually plating the electrode. During the no – wear cycle, there is a danger that nodules will grow on the electrode, thereby changing its shape.

Fuzzy Logic

Some EDM machines come equipped with fuzzy logic. Unlike Bi level logic, which recognizes a statement as either true or false. Fuzzy logic allows machine to think and react quickly to various machining conditions. These machines can lower or increase the power setting to obtain the optimum combination of speed, precision, and finish. Fuzzy logic machines constantly monitor the cut and change power settings to maximize efficiency.

Fumes from EDM

Fumes are emitted during the EDM process; therefore, a proper ventilation system should be installed. Boron carbide, titanium boride, and beryllium are three metals that give off toxic fumes when EDM is performed; these metal needs to be especially well vented.

2.2 Variants

The three electric discharge machining methods, wire, ram, and small hole EDM, all work on the principle of spark erosion. As the name indicates, the material is eroded from the work piece by means of electrical discharges that create spark. In this section all the process variants are presented.

2.2.1. Wire EDM (WEDM)

Wire EDM uses a traveling wire conductor that passes through the work piece. The wire is monitored exactly by a computer –numerically controlled (CNC) set up. Like several alternative machining tools, wire EDM removes material; however wire EDM removes material with the utilization of electricity by means of spark erosion. Therefore, material to be machine must be electrically conductive.

Rapid DC electrical pulses are generated between the wire conductor and therefore the work piece. Between the wire and therefore the work may be a shield of deionised water or kerosene, known as the dielectric. Pure water is AN nonconductor, however the tap water sometimes contains minerals that causes the water to be too conductive for wire EDM operation. To manage the water conduction, the water goes through an organic compound tank to get rid of the abundant of its elements that are accounTable for its conductivity- this is often known as deionized water. Because the machining method goes on the conduction of water tends to rise, and a pump mechanically forces the water through a dielectric tank once the water becomes too conductive.

When a comforTable voltage is applied, the dielectric fluid ionizes. Then a controlled spark exactly erodes a little section of work piece, inflicting it to melt and vaporize. These electrical pulses are perennial thousands of times per second. The controlled cooling fluid, the dielectric, cools the gasified particles. As machined part accuracy is simply too necessary for us therefore we've got to flow dielectric fluid through an excitation to stay the fluid at a relentless temperature. [2]

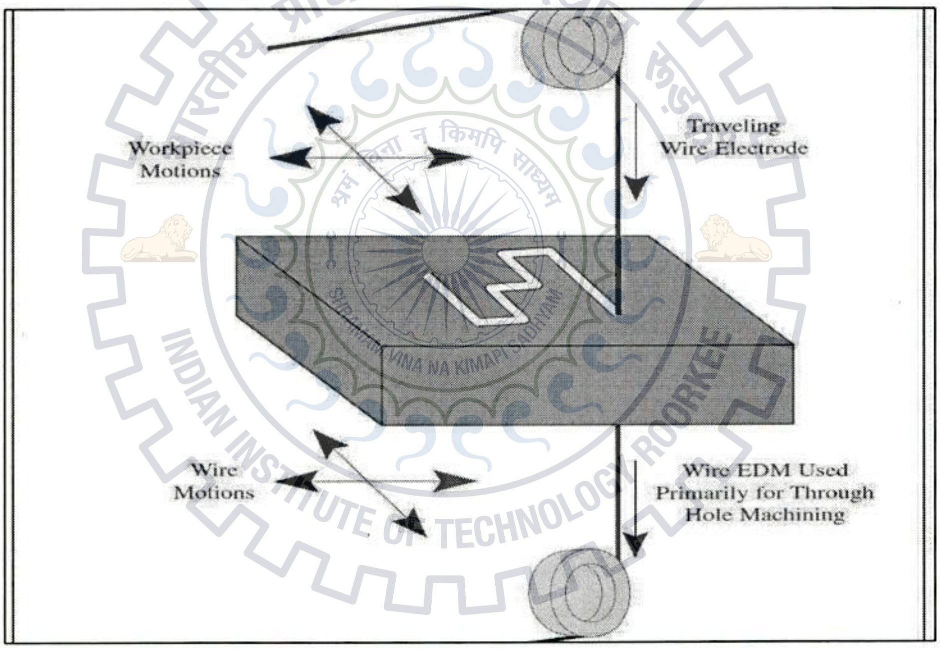


Figure 4: Wire electric discharge machining [2]

2.2.2. RAM EDM

Ram EDM also called conventional EDM uses spark erosion to remove metal. Its power supply generates electrical impulses between the tool and work piece. A small gap between the electrode and workpiece allows a flow of dielectric oil. When sufficient voltage is applied, the material oil ionizes and controlled spark soften and vaporize the work piece.

Once sufficient electricity is applied to the electrode and the work piece, the insulating properties of the dielectric oil. A plasma zone is quickly formed which reaches up to 8000° to 12000°C. The heat causes the fluid to ionize and allows sparks of sufficient intensity to melt and vaporize the material. This takes place during the controlled "on time" phase of the power supply.

The pressurized dielectric oil cools the vaporized work piece and removes the eroded material from the gap. A filter system cleans the debris from the dielectric oil. The oil goes through a heat exchanger to remove the generated heat from the spark erosion process. This heat exchanger keeps the oil at a constant temperature, which results in better part accuracy as shown in Figure 5.

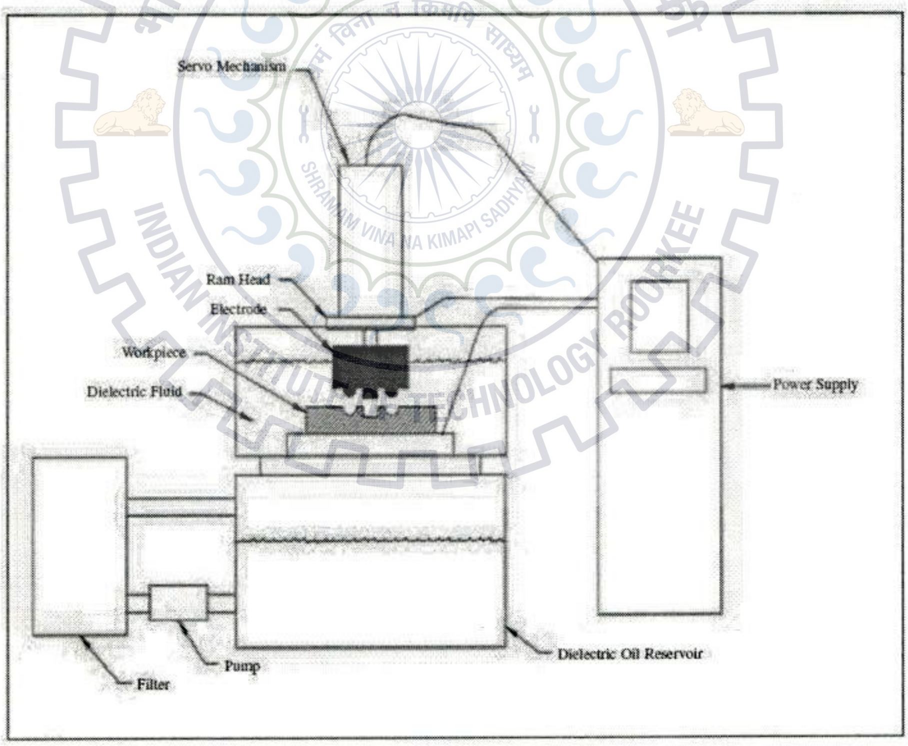


Figure 5: Ram EDM process [2]

Ram EDM, like wire EDM, is a spark erosion process. However, ram EDM produces the sparks along the surface of a formed of a formed electrode, as shown in Figure 6.

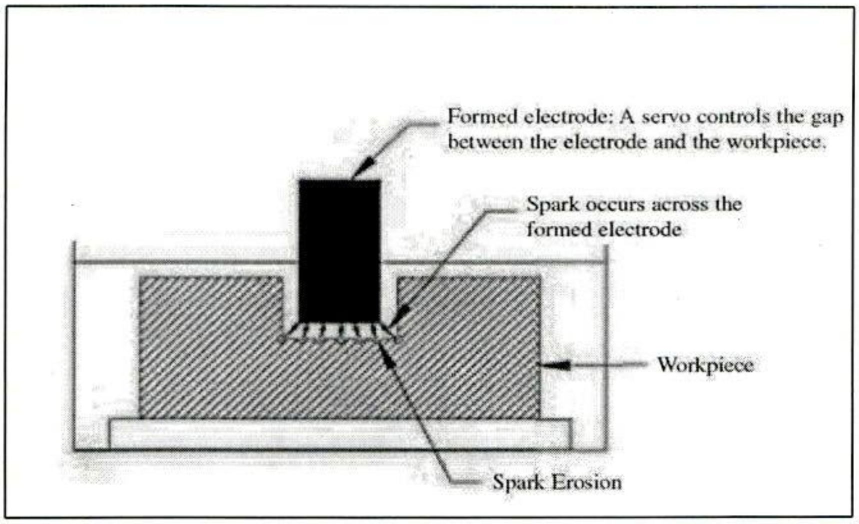


Figure 6: Ram EDM process [2]

A servo mechanism maintains the gap between the electrode and the work piece. The servo system prevents the electrode from touching the work piece. If the electrode touches the work piece, it would create a short circuit and there is no cutting.

2.2.3. Micro-EDM

Small hole EDM drilling additionally called quick hole EDM drilling, hole popper, and begin hole EDM drilling, uses a hollow conductor to drill holes by suggesting that of discharge machining by erosion material from the work piece as shown in Figure. [6] This is often in contrast to mechanical drilling, which may turn out holes simply up to 70 μm, or the micro-fabrication method like optical maser machining, which may solely produce holes of 40 μm.

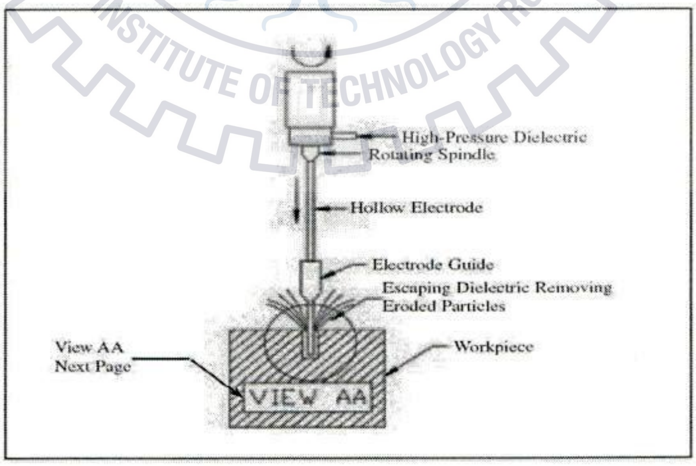


Figure 6: Micro EDM process [2]

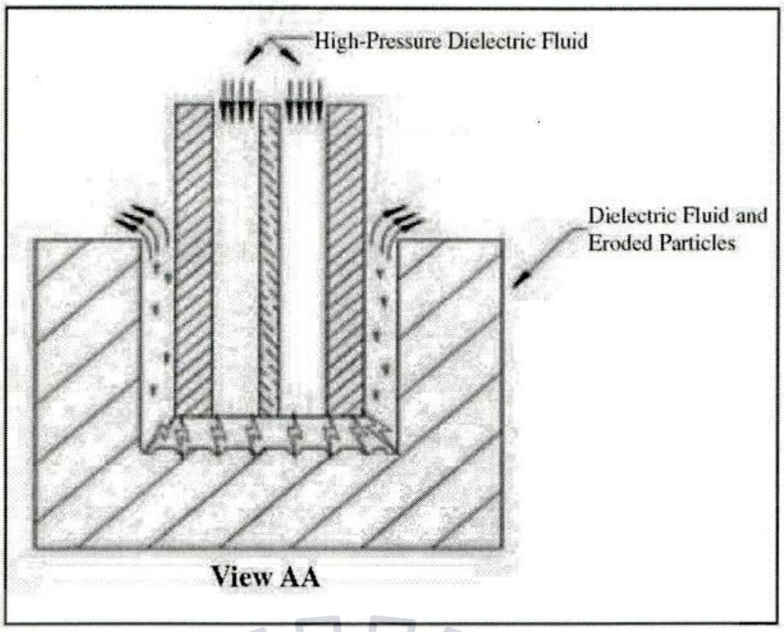


Figure 7: Rotating electrode eroding the work piece [2]

In addition, a feasibleness study of applying micro-EDM as an alternate technique for manufacturing photo-masks employed in the integrated circuit (IC) industry have been conducted.

Alternative applications embody the overall interest in developing flight EDM to resolve the machining issues of water-cooling channels employed in molds. Alternative tries have additionally been created on trajectory EDM however special equipment or advanced management mechanism is required to develop the trajectory motion of the conductor.

2.2.4 Hybrid machining processes

There is widespread tutorial and industrial interest within the event and use of hybrid machining methodology (HMP) involving high-speed machining (HSM), grinding, EDM and laser beam machining (LBM). It utilizes every commonplace, and unconventional material removal process, creating use of the combined blessings and limiting the adverse effects once applied severally. Many studies on the combined machining technology of ultrasonic machining (USM) and EDM square measure administered. Lots of varied specialized variations, discharge Texturing (EDT) used for the Texturing of cold rolled steel and Al sheets and discharge grinding (EDG) used for the manufacture of crystalline diamond cutting tools. EDG has put together been applied within the machine-driven removal of cusps and fitting of a try of dies [4].

2.3 EDM applications

This section discusses some of the applications of EDM commonly found in the industry. It also includes other experimental interests, providing a feasible expansion of EDM applications.

2.3.1. Heat-treated materials

In some applications, EDM has replaced ancient machining processes just like the fringe of heat-treated tool steels. Milled material must inside AN applicable hardness vary of but 30–35 HRC with traditional cutting tools [5]. However, EDM permits tool steels to be treated to full hardness before machining, avoiding the problems of dimensional variability, that area unit characteristic of post-treatment.

Since EDM doesn't induce mechanical stresses throughout machining, it provides a further advantage within the manufacture of intricate products. The projected technique considerably decreases the production time and significantly reduces costs of fabricating each the electrode and elements.

Courtesy Mitsubishi

Figure 8: Helical gear machining [2]

2.3.2. Carbide

Tungsten carbide, third in hardness to diamond and B_4C (boron carbide), is an especially troublesome material to machine. Aside from diamond cutting tools and diamond fertile grinding wheels, EDM presents the sole sensible methodology to machine this hardened material. [6].

Each Electrical Discharge Machining and Wire EDM are with success tested for disseminating conductive particles from aiding electrodes onto the surface of Sialon ceramics. Different kinds of ceramic materials together with oxide ceramics like zirconium dioxide (ZrO_2) and Al based oxides (Al_2O_3), that have terribly limiting electrical conductive properties have also been examined based on an equivalent technique.

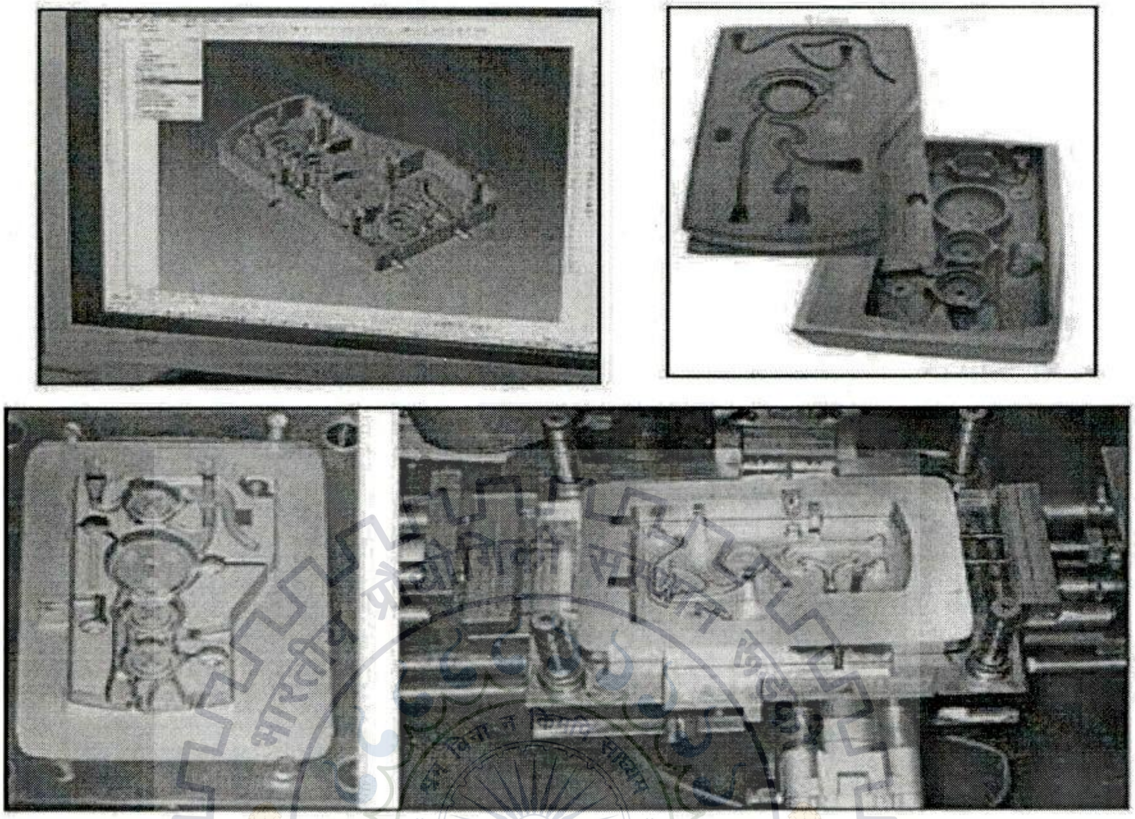


Figure 9: Medical casting from design to mold [2]

2.3.3. Modern composite materials

The development of various modern composite materials within the last decade has led to associate expansion of EDM applications. The coating of WC–Co onto components with the help of plasma spraying is used with a very high rate in the aerospace and automobile industry to stop and wear and erosion of the components. Muller [7] compared the EDM of particle reinforced metal matrix composite (PRMMC) with alternative non-conventional machining processes like LBM and abrasive water jet (AWJ). It had been found that EDM was appropriate for machining PRMMC with a comparatively small amount of sub-surface harm however the MRR was terribly slow.

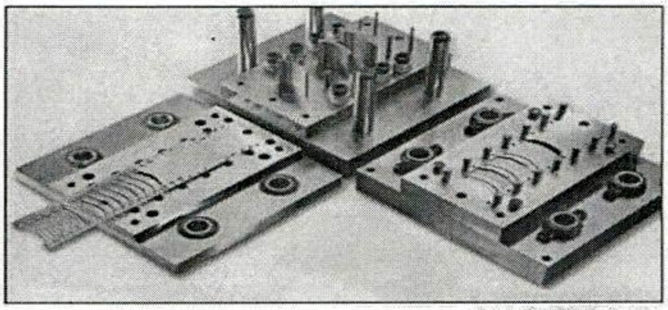


Figure 10: Punch and die wire EDM [2]

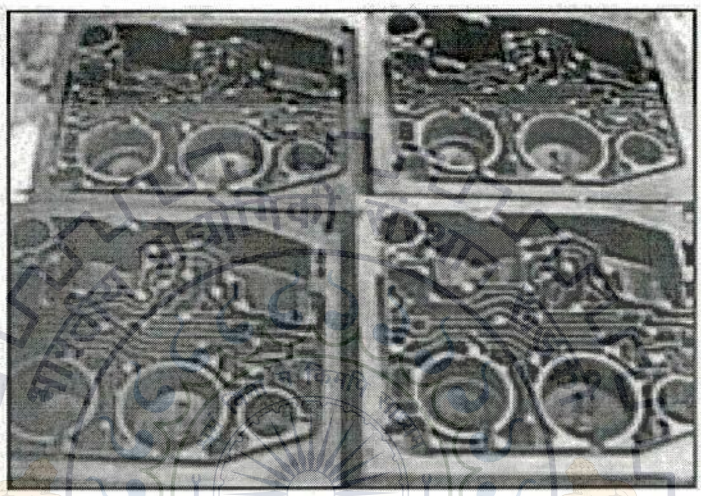


Figure 11: Abraded valve body electrodes for automatic transmission [2]

In this section, we discuss analysis areas in EDM under 3 major headings. The primary relates to machining performance measures like material removal, tool wear and surface quality (SQ). The second area describes the consequences of process parameters including electrical and non-electrical variables that are needed to optimize the random nature of the sparking method on the performance measures. Finally, research regarding the planning and manufacture of electrodes is reported.

3.1. EDM performance measures

A significant number of papers have been focussed on arriving at an optimal method of carrying out an EDM process which includes huge MRR, low tool wear rate (TWR) and adequate SQ. This section provides a study into each of the performance measures and the methods for their improvement.

3.1.1. Material removal

3.1.1.1. Material removal mechanism

Soni and Chakraverti [8] showed that quantity of elements which display diffusion towards the work-piece from electrode or vice-versa. During the process, transferred elements are either in solid, liquid or gaseous state and endure solid or gaseous phase reaction which results in the alloying at the contact surface. The kinds of eroded electrode and work piece elements along with the disintegrated products of dielectric fluid considerably have an effect on the MRM (material removal mechanism) regarding the 3 phases of sparking, specifically break down, discharge and erosion. Furthermore, if the polarity of sparking is flipped, it leads to significant changes in material removal aspects, like heavy deposition of material of electrode on the surface of work-piece.

3.1.1.2. Methods of improving the material removal rate

The utilization of CNC to EDM has helped to inspect the likelihood of application of various varieties of tools available to boost the MRR. The profile of electrodes generally engaged in EDM is three dimensional which are both costly and consume considerable amount of time to be assembled for manufacturing process. In spite of that, an experiment has been reported wherein an electrode in a frame accomplished linear as well as circular swept surfaces by restraining axial motion of electrode [9]. A similar machining technique employing a wire frame electrode was conducted to compare the time taken to machine a Cuboid cavity using a 3D solid electrode. These techniques eliminate the necessity to utilize the 3D electrode to perform the roughing operation by exchange the easy electrode to get rid of unwanted material in a complete block improving the machining efficiency and MRR.

An interesting aspect of CNC wherein it provides multi-axis movements to the electrode has been exploited through EDM to manufacture advanced three dimensional parts. Bleys et al [10] referred the novel machining technique to milling EDM (MEDM), which eliminates the necessity of manufacturing and storing varied varieties of 3D electrodes for various forms of work piece shapes. Wong and Noble introduced additional advanced motions to the cylindrical electrode by employing a micro-computer controlled x-y Table.

3.1.2. Tool wear:

3.1.2.1. Tool wear process

There are stark similarities between MRM and tool wear process (TWP) as both work-piece and tool are supposed to be an agglomeration of electrodes in EDM.

Mohri et al [11] claimed that during sparking, condensation of carbon on to the surface of electrodes affects tool wear, the source of carbon being hydrocarbon dielectric. They conjointly argued that the incapability of carbon precipitation in complex areas of electrode leads to quick wear at the corner of electrode.

3.1.2.2. Techniques of minimizing the tool wear rate

In order to take care of tool wear, the revolution of electrode relative to the work-piece is the most commonly employed strategy. In this technique, the electrode undergoes a planetary motion which leads to the development of competent flushing action that improves the part accuracy and operation efficiency. The orbiting technique additionally reduces the quantity of various electrodes needed for initial roughing and final finishing operations. So as to optimize the electrode trajectory in real-time, a computer integrated planetary machining strategy based on continuous adaptation of machining parameters was developed.

Analogous strategies have been enforced to MEDM (Milled EDM), which is often accomplished in lean sheets with the help of tube-shaped electrodes to compensate tool wear. Bleys et al. [10] Initially arrived at a diminished tool length through pulse analysis and afterwards restrained the downward feeding movement during the whole operation in order to reduce tool wear over a stipulated time period.

3.1.3. Surface quality

3.1.3.1. Surface quality analysis

The electrical discharge machined (EDMed) surface is formed from 3 distinctive layers composing of white layer/recast layer, heat affected zone (HAZ) and genuine parent metal. Since the white layer is the outermost layer hence unprotected from atmosphere, the surface properties of work-piece are largely dependent upon it. P.C. Pandey et al. [12] discovered the presence of micro-cracks and high tensile residual stresses on the EDMed surface caused by the hot temperature gradient. The detrimental impact of spark energy furthermore gave some useful observations regarding the multiple surface imperfections inside the recast layer which were caused in work-piece under fatigue phenomenon.

Further, the EDMed surface reports a comparatively elevated micro-hardness values, whose possible explanation may be the out-migration of carbon from the oil dielectrics to the work surface resulting in the formation of iron carbides throughout the white layer. The concentration of carbides, each as the surface layer of the work and as fine powder scrap, depends on the frequency and polarity of the applied current alongside different process parameters like pulse shape, gap spacing and dielectric temperature.

3.1.3.2. Methods of improving surface quality

(i) Surface alloying

Many researchers have described a unique approach regarding surface amalgamation in which a composite electrode is employed to improve the work-piece characteristics. The composite electrode is additionally referred to because the green compact, sintered or powder metallurgy (PM) electrode. Its low thermal conductivity permits the composite material to disintegrate from the electrode and alloy onto the workpiece surface, producing less cracks, high corrosion and wear resistance. Selma et al [13]. Implemented a different analysis on the PM electrode and obtained the effect of the impact of different operating parameters to attain the desired properties of work-piece.

(ii) Powder additives

Lately, suspension of powders in dielectric fluid has led to improvement of surface properties. These particles lower the critical strength of dielectric fluid and generates an elevated spark probability. This leads to an ease in the ignition process. As a result, it increases the MRR, reduces the TWR and improves the sparking efficiency, producing a strong corrosion resistant to EDMed surface. Moreover, the presence of powders in the dielectric fluid increases the micro-hardness and reduces the micro-cracks on the EDMed surface due to a reduction of losing alloying elements residing onto the workpiece.

M.L. Jeswani [14] reported a development in machining stability and discharge transitivity during EDM because of reduction in arcing frequency caused due to the even distribution of gap debris.

(iii) Surface finish simulation

A couple of EDM modelling tools which connects the process parameters with surface finish have been developed over two decades. Jeswani et al. [14] investigated the results of the workpiece and electrode materials upon SR and developed an experimental paradigm, whose concentration was solely on pulse energy. It had been accomplished that the impact of discharge current is more upon the MRR whereas the pulse-on time largely controls the SR and white layer.

3.2. EDM process parameters

This section focuses on the effects of operating parameters on various performance measures.

3.2.1. Effect of electrical parameters

The consequences of electrical criterion are hard to elaborate experimentally owing to the characteristic thermal properties of the EDM process. Thus, this section describes research in the areas of optimization, monitoring and control of the various electrical parameters on the performance measures.

3.2.1.1. Parameter optimization

Traditionally, the choice of the most favorable process parameters was based on the expertise or handbook values that produced inconsistent machining performance. However, the optimization of parameters currently depends on process analysis to identify the result of operational variables on achieving the required machining characteristics.

3.2.1.2. Process monitoring and control

(i) Pulse parameters

The recognition of different pulses is many a times criteria on which real-time audit and restraining of EDM parameters is done. EDM pulses are organized as open, spark, arc, off or short pulses, which depend upon obstruction in the ignition, and impart effect upon the Material removal rate, SR and part accuracy. Therefore, the recognition and classification of the different pulses provide a viable option of monitoring and controlling the sparking process by measuring the related gap voltage and current.

Weck and Dehmer [15] studied the effect of different pulses on MRR together with TWR and developed an adaptive gap controller, which reduces the number of undesirable pulses.

(ii) Time domain

Several authors [15-16] argued that the gap voltage is not a good indicator of the dynamic responses taking place at the spark gap largely due to the high frequency (HF) noise component. These authors instead advised to keep on checking the ratio of time of dynamic arc measured by pulse-on time. This leads to display of tendency in the direction of abominable arcing.

(iii) Fuzzy logic

Amid the EDM operation, on applying fuzzy logic to a robust control system will provide a steady pulse. Many authors claimed that the fuzzy logic control implements a control strategy that is adopted by a skilled operator to maintain the desired machining process [16].

3.2.2. Effect of non-electrical parameters

Besides electrical parameters, there are certain non-electrical parameters which are the primary reason for obtaining optimized measures of performance for the electrode and workpiece. These include circular rotation of work-piece along with dielectric fluid. This section discusses the impact of these parameters on the different performance measures.

3.2.2.1. Flushing of dielectric fluid

The flushing of the dielectric during the sparking process has an adverse effect on the EDM performance measures. Lonardo[17] revealed Material removal rate was immensely influenced because of flushing in the course of roughing and TWR, in the course of finishing process, it influenced the SR. The crack density and recast layer are also characterized by flushing rate. It can be minimized by attaining optimizes rate of flushing. In addition, the various properties of the stuff fluid additionally play a crucial part in washing away the junk in between gaps during manufacturing. Tool wear and MRR are dependent on the breakdown resistance, conductivity, viscosity, flash point, health and safety factors of dielectric fluids. The prospect of application of water instead of kerosene as the working fluid for micro-EDM has been investigated.

3.2.2.2. Rotating the workpiece

Besides the dielectric fluid flushing process, the EDM process is also influenced by the approach through which rotatory motion to the discharge process is applied. HEDM (hybrid EDM) has also been investigated for manufacturing of miniscule components [18]. Moreover, an electrode fabrication system using wire electro-discharge grinding (WEDG) was installed in these prototype machines making it possible to fabricate the complex micro-electrode at the same machine and maintain the concentricity of the parts produced.

3.2.2.3. Rotating the electrode

Similarly, the rotary motion has been introduced to the electrode through which the capability measure of EDM operation could be enhanced. It has been found to enhance MRR & SR and hence proves to be impressive flushing of gap strategy. The same alloying effect of migrating material elements from the workpiece and tool is also observed, in relation to the morphology, chemical composition and size distribution of debris, when using rotating electrodes. Soni and Chakraverti [19] compared the different capability measures of whirling electrode when compared with the immobile electrode. The results brought out an enhancement in MRR owing to superior action and sparking efficiency with lesser wear of the tool along with increased SR.

3.3. Electrode design and manufacture

This section describes the different computer-aided systems that have been experimentally implemented in the design of the electrode. The major research interest in the production of electrodes using the rapid prototyping technique is also included in the section.

3.3.1. Computer assisted electrode design

The design and manufacture of an electrode have progressed along with the technological advancement made in the various computer-aided systems. A CAD system is capable of creating the electrode and holder designs from the workpiece 3D geometry and identifying any undesirable sharp corners on the designs, which are difficult to produce, by measuring the surface angle along the edges.

After a comprehensive study of the existing literature, a number of gaps have been observed in the field of electrical discharge sawing. It is observed that research area of EDS process is still in the experimental stage. Although, the process is feasible but it's compatibility for all types of advanced materials is still to be investigated. Some of the gaps and opportunities found after the extensive literature review are highlighted in the following sections.

4.1. Optimizing the process variables

The EDM process characterizes high speculative nature owing to its complex discharge techniques. Hence, optimizing the process of sparking proves to be a challenging task. The optimization of the process includes obtaining the relation between various process variables and measures of performance. It involves maximizing the MRR, along with minimizing the TWR and delivering the required SR. In several cases, S/N ratios together with the analysis of variance (ANOVA) techniques are used to measure the amount of deviation from the desired performance measures and identify the crucial process variables affecting the process responses. The process variables include electrical and non-electrical parameters, which have received quite a substantial amount of research interest. Therefore, with the regular research attempts made in order to develop superior understanding of the initialization and evolution of process of discharging, the distinct methods for optimizing the peculiar process variables will remain to be the dominant field of fresh research in order to reduce the speculative nature of the EDM process.

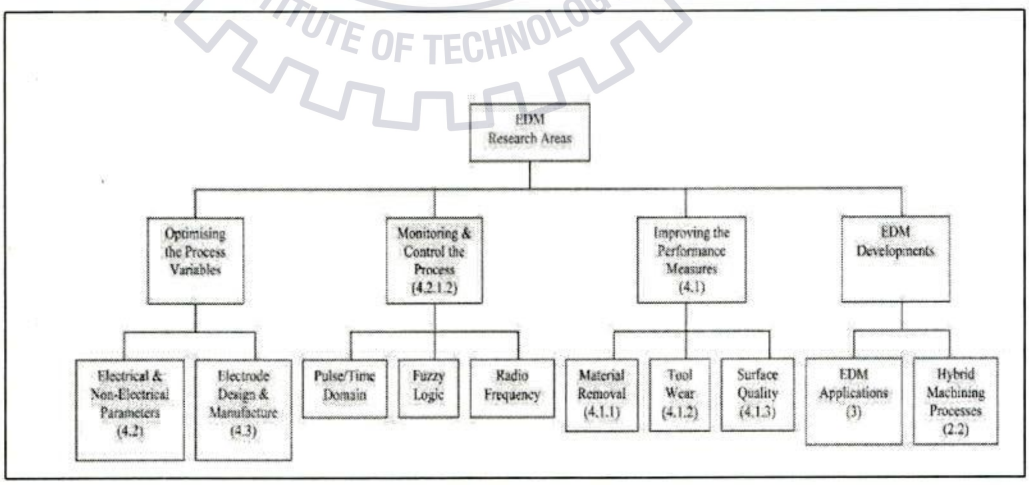


Figure 12: Classification of major EDM research areas [21]

4.2. Improving the performance measures

As shown in Fig. 13, a significant amount of research work have been concentrated on the progress imparted to the performance indices, like MRR, TWR and SR. Most of these investigations have diverged from the conventional sparking aspect, delivering superior manufacturing efficiency and enhanced measures of performance. This is partly due to the application of CNC to EDM in order to assist the MRM, along with developing the tool wear compensation techniques.

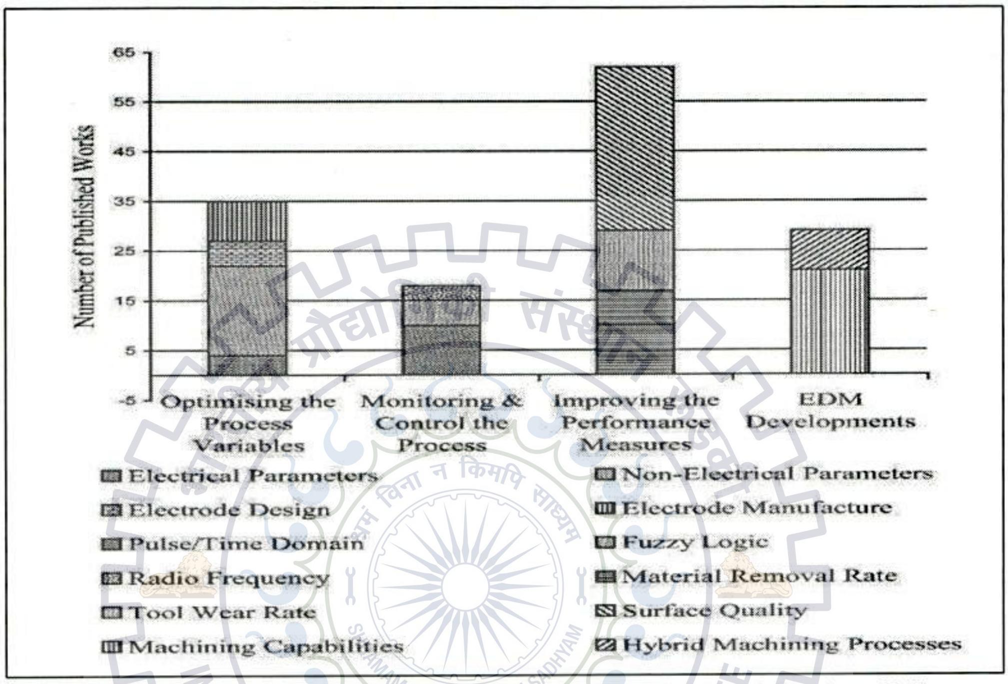


Figure 13: Distribution of the collected EDM research publications [21]

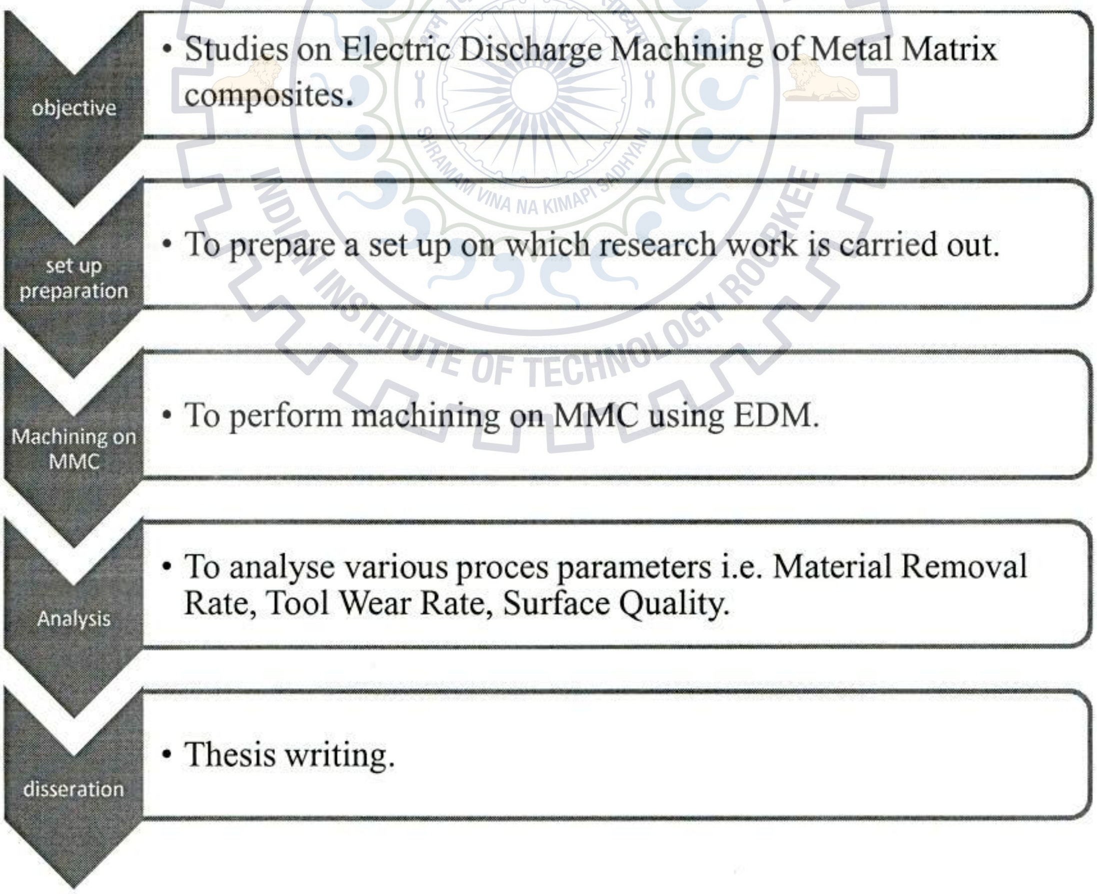
4.3. EDM developments

The different advances created on the EDM machine have conjointly progressed with the growing applications of EDM process. EDM has been continuously in application in the automotive, aerospace, mold, tool and die making industries. It's conjointly created a major inroad within the medical, optical, dental and jewellery industries, and in automotive and aerospace Research and Development areas. These operations demand tight manufacturing requirements, like the machining of HSTR (high strength and temperature resistive) materials, which generate consequential interest in research and encourage EDM machine makers to enhance the machining characteristics. In addition, shorter product development cycles and growing price pressures have forced the die and mold making industries to extend the EDM efficiency.

One of the distinctive choices of improving the machining performance involves the HMP (hybrid machining processes) combining EDM process with other material removal processes. The foremost, well-liked and extremely effective arrangement includes the USM is delivering ultrasonic vibration to the electrode, which assists the sparking and flushing operations. However, the present trend in tool and die manufacturing is towards replacing the EDM process with new machining techniques like HSM (high speed machining). HSM method is simply as capable because the EDM method in machining hardened materials with 40–60 HRC. Therefore, HMP involving EDM will continue to draw intense analysis interests seeking innovative ways in which of improving the machining performance and increasing the EDM applications.

4.4 Methodology to perform the work

Now a days there is a massive demand of light weight materials having great strength (high strength to weight ratio) with some complicated geometry. To take care of this market demand, researchers have developed materials known as MMC's (metal matrix composites) which possess such kind of properties, but it is difficult to machine MMC's with conventional machining operation. So to fulfil this market demand this research work will be dedicated to machine MMC's by using a new machining process known as electric discharge sawing.



4.5 Objective of the present work

An exhaustive review of the existing literature has helped to set the following objectives of this research work which are outlined as follows;

- The main objective of the present work is to develop (design and fabricate) EDS set-up by modifying the existing EDM facility.
- To perform an experimental investigation on EDS for metal matrix composites processed by stir casting process.
- To establish an optimum combination of process parametes of EDS which provide maximum material removal rate (MRR) and minimum tool wear rate (TWR).

CHAPTER 5 DEVELOPMENT OF EXPERIMENTAL SETUP FOR ELECTRICAL DISCHARGE SAWING (EDS) PROCESS

In this chapter, an Electrical Discharge Sawing set-up has been designed and developed. All the parts used in the setup are in house production (manufactured in a Machine tool lab in MIED at IIT Roorkee).

5.1 Design and Development of EDS Setup

There still exist numerous difficulties in cutting advanced materials, super alloys and metal matrix composite materials. EDS is a competent sawing process for cutting difficult to cut materials. In this chapter, a modified setup has been designed and developed. The sawing process has been investigated with the developed setup. The EDS setup has been developed in a Machine tool lab in MIED at IIT Roorkee. The developed setup has been attached to an existing z – axis NC electrical discharge machining setup. The EDS process setup has been designed keeping in mind the crucial process mechanism as well as the logical requirement of various parts. The design of every part requires general selection criteria such as light weight, slight vibration should be there during the operation.

This type of operation is normally unsTable, and the efficiency is very high. However, this process has a key problem caused by setup vibration at high speed, which appreciably degrade the machining accuracy. The process performance in terms of maximization of material removal rate, minimization of the TWR (tool wear rate) has been experimentally investigated.

5.2 Available Mechanism to Convert Rotary Motion into Reciprocating Motion

1. Slider crank mechanism
2. Scotch yoke mechanism
3. Cam and follower mechanism
4. Rack and pinion mechanism

5.2.1 Scotch yoke mechanism

Mechanism: Scotch yoke is a mechanism for converting the linear motion of a slider into rotational motion crank or vice-versa. This is a four link mechanism in which two turning pair and two sliding pairs are used for obtaining desired useful motion.

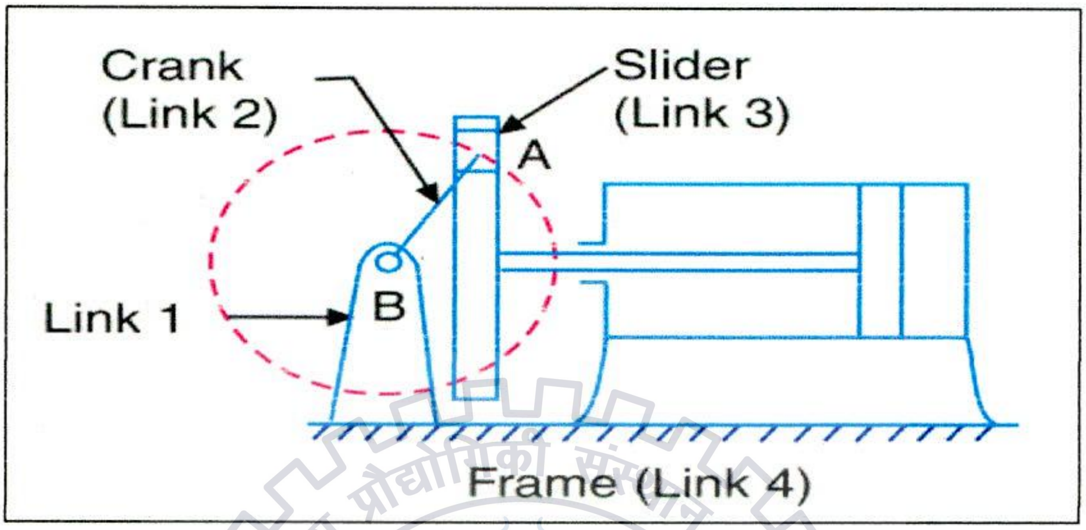


Figure 14: Schematic diagram of scotch yoke mechanism [22]

Advantages and disadvantages

Advantages

- ❖ Fewer moving parts: in scotch yoke mechanism there are few moving parts as compared to the slider crank mechanism which aids advantage to reduce vibrations and fluctuations.
- ❖ Smoother operation: scotch yoke mechanism gives smooth operation and continues sine curve is obtained during the motion of mechanism.
- ❖ The use of the connecting rod is eliminated when compared to slider crank mechanism which is responsible for high frequency vibration in slider crank mechanism.

Disadvantages

- ❖ Rapid wear of the slot in the yoke caused by sliding friction and high contact pressures.

5.3 Design and selection of the components

In engineering design, many times the designer has to specify the size of product because the company manufactures several different models of the product according to load, RPM (rotation per minute), working hour, etc. These referred numbers were first introduced by French balloonist and engineer Charles Renord in the 19th century (Bhandari, 1999; P.S.G., 1999).

According to completely different necessities, half is nominal by size, variety and can even be selected consistent with design specifications. Within the method of developing EDS created, v – belt, the motor, sawing tool, disc design, guideways, sliding bar, tool holder, vertical and horizontal supports and v – pulley has been selected. Owing to the limitation of the producing strategies, it's out of the question to machine an element to a given dimension accurately; the elements are so manufactured that lie between the most and minimum tolerance limits. Therefore, throughout the producing of this setup, all dimensions are nominal with tolerance. Within the producing of set- up, operations are performed on different machines.

List of parts used in the mechanism.

- Electric Motor
- Auto Regulator
- Disc (as crank)
- V – Pulleys
- V – Belt
- Cylindrical rod (pin)
- Sliding Yoke
- Washer
- Sliding bar
- Guideways
- Guideways upper plate
- Supports in vertical plane
- Supports in horizontal plane
- Tool holder
- Copper tool

5.3.1 Electric motor

Electric motor is a very important part of the attachment. It is located on a flat aluminium plate. The motor is used to drive, scotch yoke mechanism with the help of a belt, through the shaft, the tool can be reciprocated and used to perform machining. According to the requirement of the tool speed, we can control the speed with the help of auto regulator.

Figure 15: Actual view of the electric motor

Selection of Motor: In EDS setup, smooth power transmission is required because fluctuation in the speed affects the spark and maximum time of operation. Therefore, according to experimental parameters, we have selected 0.5 kW motor. A single phase motor of 0.5 kW and 8000 RPM (AC/DC (0.75 amp)), can provide the speed of the shaft in the range of minimum to maximum RPM with the help of auto regulator.

5.3.2 Auto regulator

Auto Regulator directly affects the speed. The power is supplied through the auto regulator to motor and through the motor we get the reciprocating motion of the EDS tool by using scotch yoke mechanism. Through the regulator we can control the speed of the EDS tool during the machining operation.

5.3.3 Disc design

Since the disc is subjected to rotation with a constant angular speed ω. Which is known to us (i.e. We set it according to our desire) and the inner diameter is also fixed (i.e. According to our designed shaft diameter) so we should have to get the reasonable outer diameter by applying design and strength of material equations.

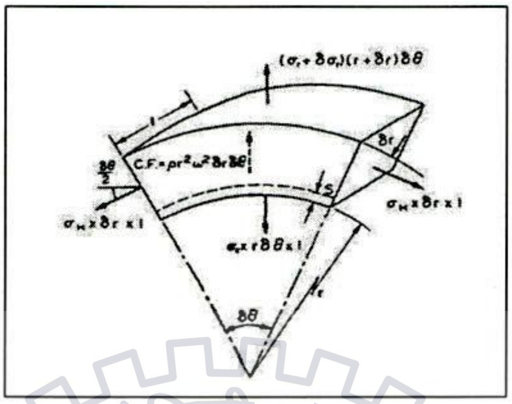


Figure 16: Forces acting on a general element in a rotating disc

Consider an element of a disc at radius *r* as shown in Figure 16. Assuming unit thickness:

The volume of the element = rδθ*δr*1= rδθδr

Mass of element = ρrδθδr

Therefore the centrifugal force acting on the element

$$= mr\omega^2$$

$$= \rho r\delta\theta\delta r\omega^2 r = \rho r^2 \omega^2\delta\theta\delta r$$

Now for equilibrium of the element radially

$2\sigma H\delta r \sin.5\theta + \sigma_r r\delta\theta - (\sigma_r + \delta\sigma_r)(r + \delta r)\delta\theta = \rho r^2\omega^2 \delta\theta\delta r$

If **δθ** is small,

$$\sin\frac{\delta\theta}{2} = \frac{\delta\theta}{2} \text{ radian}$$

Therefore in the limit, as $\delta r \rightarrow 0$ (and therefore $\delta\sigma_r \rightarrow 0$) the above equation reduces to

$$\sigma H - \sigma r - r\frac{d\sigma r}{dr} = \rho r^2 \omega^2$$

After integrating and solving for constants and apply boundary conditions we get following two equations for hoop stress and radial stress. (Please refer to book: E.J. Hearn, Mechanics of Materials 2. Butterworth - Heinemann, 1997).

$$\sigma_r = A - \frac{B}{r^2} - (3+\nu)\frac{\rho\omega^2 r^2}{8}$$

$$\sigma_H = A + \frac{B}{r^2} - (1+3\nu)\frac{\rho\omega^2 r^2}{8}$$

In our case we have aluminium 6063 as a material of the disc.

Table 1: Mechanical properties of Al 6063

Tensile strength, (MPa)	100
Hardness (Vickers), (HV)	73
Density (g/cm^3)	2.7

Assumptions:

Factor of Safety: 3

Radial stress at inner radius (MPa): 10

Maximum rotational speed (RPM): 2000

Poison's ratio: 0.35

Inner Radius (mm): 6

Yield strength: 500 MPa

So induce stress should be less than maximum permissible stress.

$$\sigma_{ind} \leq \sigma_{per}$$

At inner radius we apply both equations.

$$\frac{500*10^{\wedge}6}{3} = A + \frac{B}{.006^{\wedge}2} - (1+.35*3)*\frac{2700*(33*3.14)^2*.006^{\wedge}2}{8}$$

$$\frac{-10*10^{\wedge}6}{3} = A - \frac{B}{.006^{\wedge}2} - (1+.35*3)*\frac{2700*(33*3.14)^2*.006^{\wedge}2}{8}$$

So after solving it, we got constants

A= 78340481 and B= 19874.89

Now we put the above value of constants into the equation and apply the radial stress equation to find out radius where radial stress is zero.

We get outer radius value is 0.6 meters

From where we concluded that our disc of unit thickness is safe upto radius 0.6 meters

After that it will fail.

So we choose disc of radius 35 mm by considering the space restriction in the EDS set-up.

Table 2: Different operations used in production of disc

Operation no	Operation	Machine Tool	Tool used
1.	Marking	-	Scale and marker
2.	Cutting	Walker turner band saw Machine	Walker turner band saw blade
3.	Drilling	Lathe Machine	Drill bit
4.	Turning	Lathe Machine	Single point cutting tool
5.	Internal threading	AdjusTable Tap Handle	Tap
6.	Finishing	Lathe Machine	Amber paper and filing
7.	Inspection	-	Vernier scale

Figure 17: Production drawing and actual image of disc.

5.3.4 V-Pulleys

There are two pulleys used in the attachment and both are made of aluminium. The pulley diameter should be carefully selected in order to have the desired velocity ratio. The production of v-pulley has been achieved by performing different machining operations as shown in the Table 3.

Table 3: Different operations used in production of v-pulley

Operation no	Operation	Machine Tool	Tool used
1	Turning	Lathe	Tuning tool, outside calliper
2	Grooving	Lathe	Grooving tool, Vernier calliper
3	Drilling	Lathe	Drill, inside calliper
4	Finishing	Lathe	Amber paper and filing
5	Inspection	-	Vernier scale

5.3.5 Selection of belt

In an EDS set-up, v- belt has been used for transmitting power from driver to driven pulley.The belt is provided with initial tension to avoid slip. The v- belt has a trapezoidal cross section. Therefore, it is in contact with the side of pulley also. V- belt drive permits large speed ratios and provide long life which are its salient advantages. To achieve more friction and to enhance the contact area so that there is no slip and better power transmission we use cross belt. They are easily installed and removed, quite, and require low maintenance. Conventional belts are available in A, B, C, D, and E sections, and in certain sizes for low-horsepower transmission.

In the present set- up; for motor power = 0.5 kW, 'A' type belt is selected as shown in Table with belt width = 13 mm and belt thickness = 8 mm.

Table 4: Dimensions of standard v- belts according to IS: 2494-1974 (Bhandari, 1999)

Type of v-belt	Power transmitted (kW)	Minimum pulley pitch diameter [D] (mm)	Top width [b] (mm)	Thickness [t] (mm)
A	.7-3.5	75	13	8
B	2-15	125	17	11
C	7.5-75	200	22	14
D	20-150	355	32	19
E	30-350	500	38	23

5.3.6. Cylindrical rod (pin)

This is used to connect disc to yoke. It is made of brass so that wear of the pin should be less and give rigid connection with a disc by assembly with the help of threads.

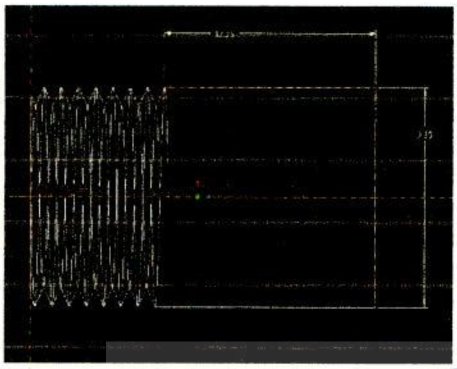


Figure 18: Production drawing and actual view of cylindrical rod

Table 5: Different operations used in production of cylindrical rod

Operation no	Operation	Machine Tool	Tool used
1		-	
2	Turning	Lathe Machine	Single point cutting tool
3	External threading	AdjusTable Die handle	Die
4	Finishing	Lathe machine	Amber paper and filing
5	Inspection	-	Vernier scale

5.3.7 Sliding yoke

The yoke is slotted link in the scotch yoke mechanism. It is rigidly connected with the sliding bar and making a sliding pair with the cylindrical pin. This link wears out very fast because of nature, of the pair is a lower pair (i.e. Sliding pair). This is made of aluminium.

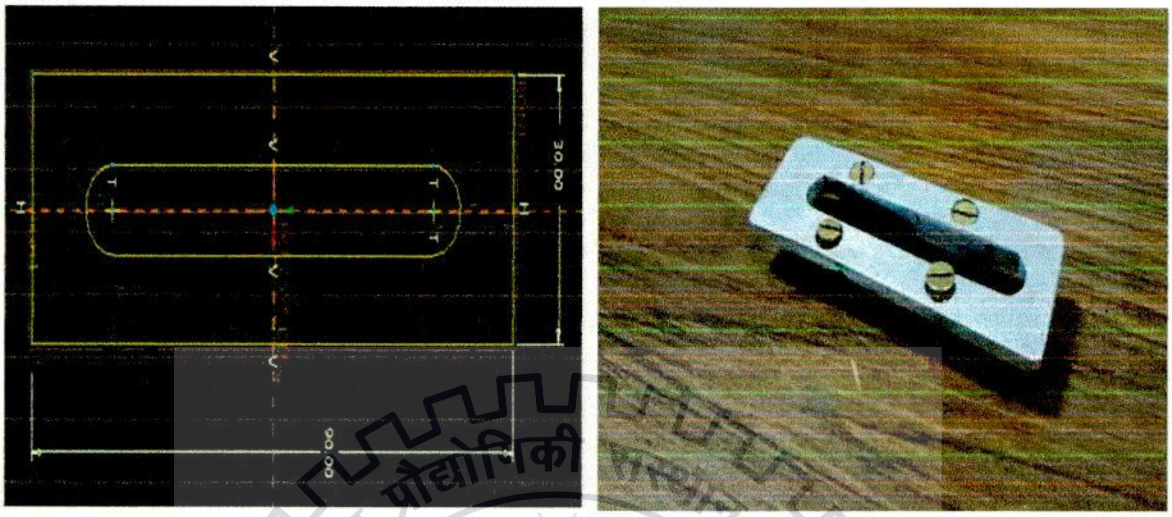


Figure 19: Production drawing and actual view of sliding yoke.

Table 6: Different operations used in production of sliding yoke

Operation no	Operation	Machine Tool	Tool used
1.	Marking	-	Scale and marker
2.	Cutting	Shaper Machine	Single point cutting tool
3.	Drilling	Drilling Machine	Drill bit
4.	Cutting	Hand hacksaw	Hacksaw blade
5.	Finishing	Bench filing	Amber paper and filing

5.3.8 Sliding bar

Sliding bar is the link of scotch yoke mechanism which works as a piston. This makes the sliding pair with the guideways. This is made of aluminium. This link provides linear to and fro motion. Sliding bar slides in the guideways and provide desired motion i.e. reciprocating motion.

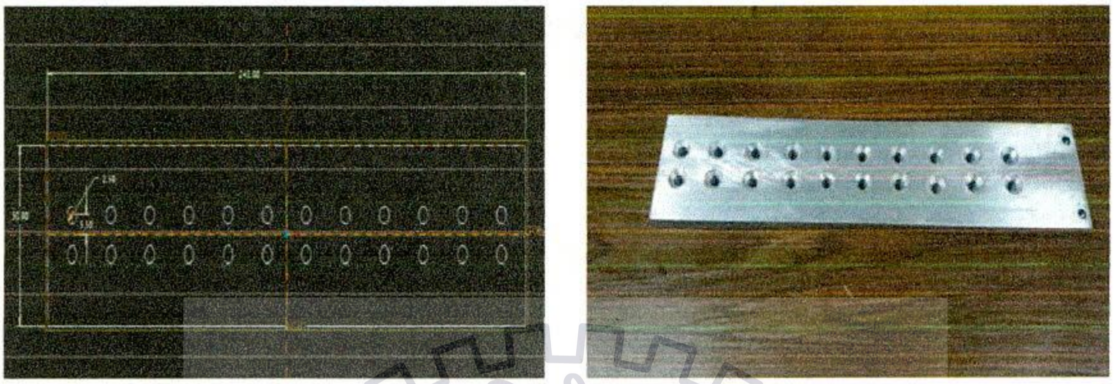


Figure 20: Production drawing and actual view of sliding bar.

Table 7: Different operations used in production of sliding bar

Operation no	Operation	Machine Tool	Tool used
1.	Marking	-	Scale and marker
2.	Cutting	Power hacksaw	Power hacksaw blade
3.	Center punching	-	Center punch
4.	Drilling	Drilling Machine	Drill bit
5.	Finishing	Bench filing	Amber paper and filing
6.	Inspection	-	Vernier scale

5.3.9 Guideways

Guideways are responsible for the linear to and fro motion of sliding bar. It guides the sliding bar to generate desired motion. This is also made of aluminium.

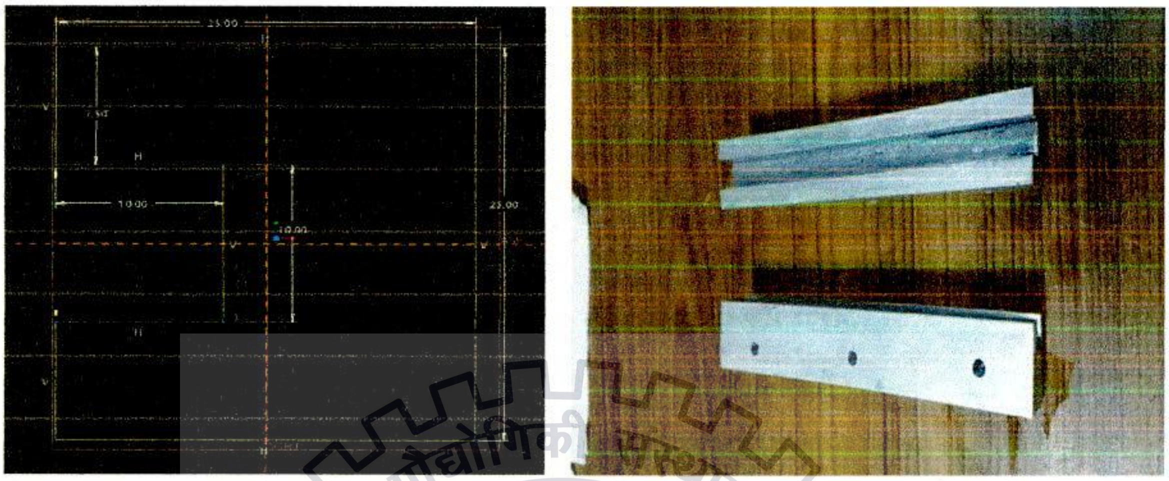


Figure 21: Production drawing and actual view of guideways.

Table 8: Different operations used in production of guideways

Operation no	Operation	Machine Tool	Tool used
1.	Marking	-	Scale and marker
2.	Milling	Milling machine	Plain milling cutter
3.	Center punching	-	Center punch
4.	Drilling	Drilling Machine	Drill bit
5.	Internal threading	AdjusTable tap handle	Tap
5.	Finishing	Bench filing	Amber paper and filing
6.	Inspection	-	Vernier scale

5.3.10 Guideways upper plate

Guideways upper plate connects both the guide way with the help of nut and bolts. This should be a rigid member. This also connects the top Al plate with a Perspex sheet as a connector between the two. It should be reasonably thick, so that no bend during machining operation which results in machining inaccuracies.

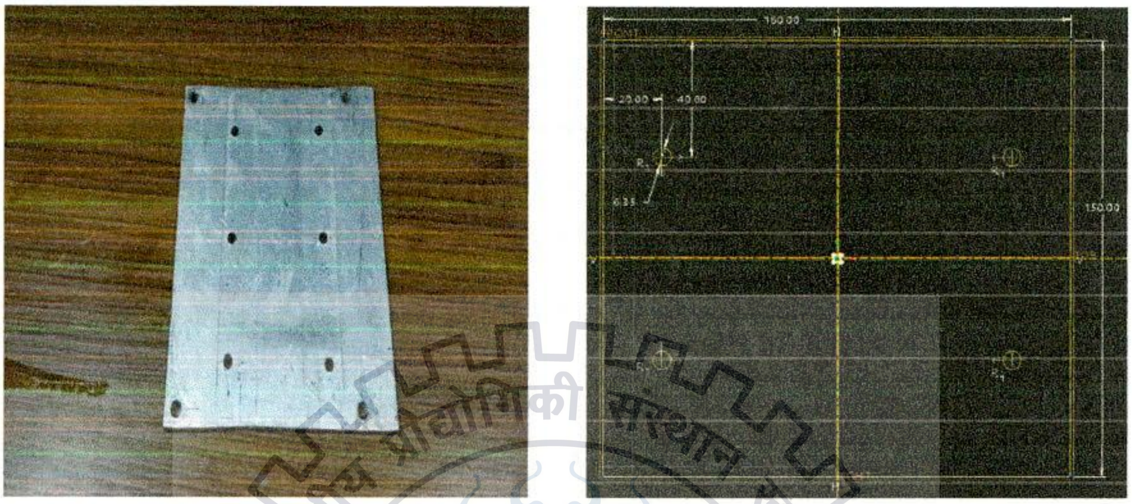


Figure 22: Production drawing and actual view of guideways upper plate.

Table 9: Different operations used in production of guideways upper plate

Operation no	Operation	Machine Tool	Tool used
1.	Marking	-	Scale and marker
2.	Center punching	-	Center punch
3.	Drilling	Drilling Machine	Drill bit
4.	Finishing	Bench filing	Amber paper and filing
5.	Inspection	-	Vernier scale

5.3.11 Supports in vertical plane

Supports in the vertical plane are used to connect the top Al plate with guideways plate. This should be rigid and stiff because it has to bear the loads of the set-up. Rigidity should be maintained during machining operation to avoid any kind of inaccuracies.

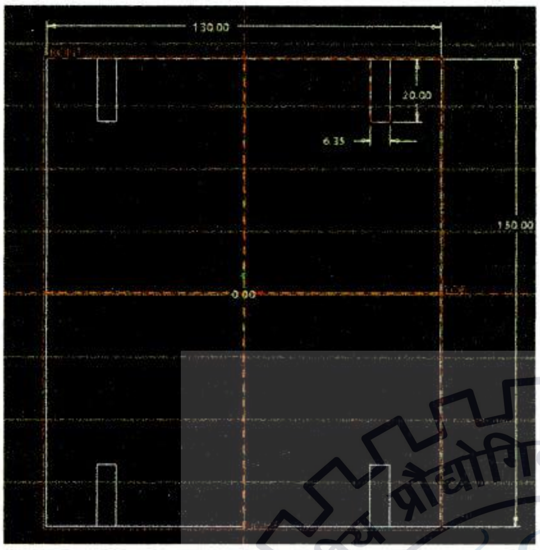


Figure 23: Production drawing and actual view of supports in vertical plane.

Table 10: Different operations used in production of supports in the vertical plane

Operation no	Operation	Machine Tool	Tool used
1.	Marking	-	Scale and marker
2.	Center punching	-	Center punch
3.	Drilling	Drilling Machine	Drill bit
4.	Internal threading	AdjusTable tap handle	Tap
5.	Finishing	Bench filing	Amber paper and filing
6.	Inspection	-	Vernier scale

5.3.12 Supports in horizontal plane

Supports in the horizontal plane are required to reduce the vibration in the set- up and for the smooth operation of set-up during machining operations.

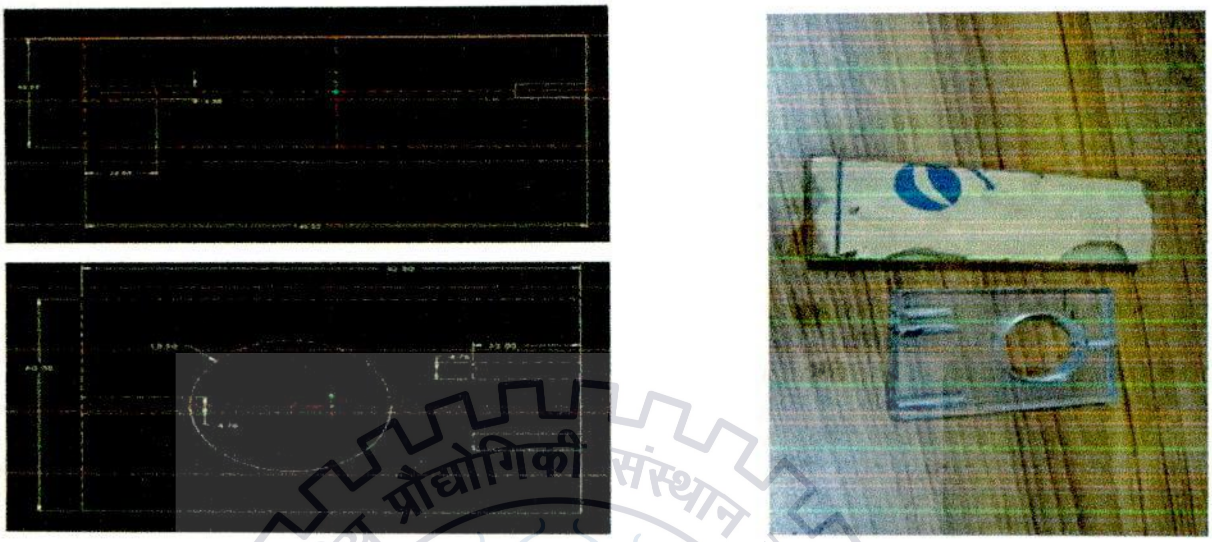


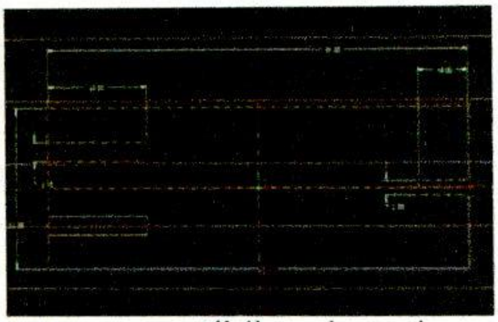
Figure 24: Production drawing and actual view of supports in horizontal plane.

Table 11: Different operations used in production of supports in the horizontal plane

Operation no	Operation	Machine Tool	Tool used
1.	Marking	-	Scale and marker
2.	Shaping	Shaper machine	Single point cutting tool
3.	Turning	Lathe machine	Cutting tool
4.	Center punching	-	Center punch
5.	Drilling	Drilling Machine	Drill bit
6.	Internal threading	AdjusTable tap handle	Tap
7.	Finishing	Bench filing	Amber paper and filing
8.	Inspection	-	Vernier scale

5.3.13 Tool holder

Tool holder gives the proper seat to the tool. It should be rigid and require precise manufacturing because little inaccuracy in this directly affects the machining accuracy.



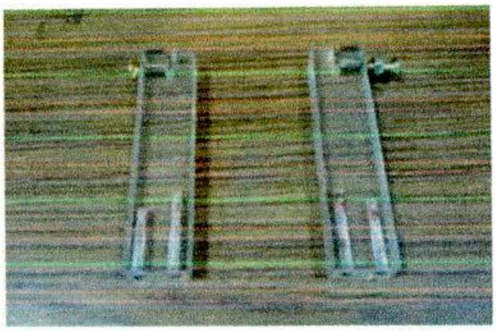
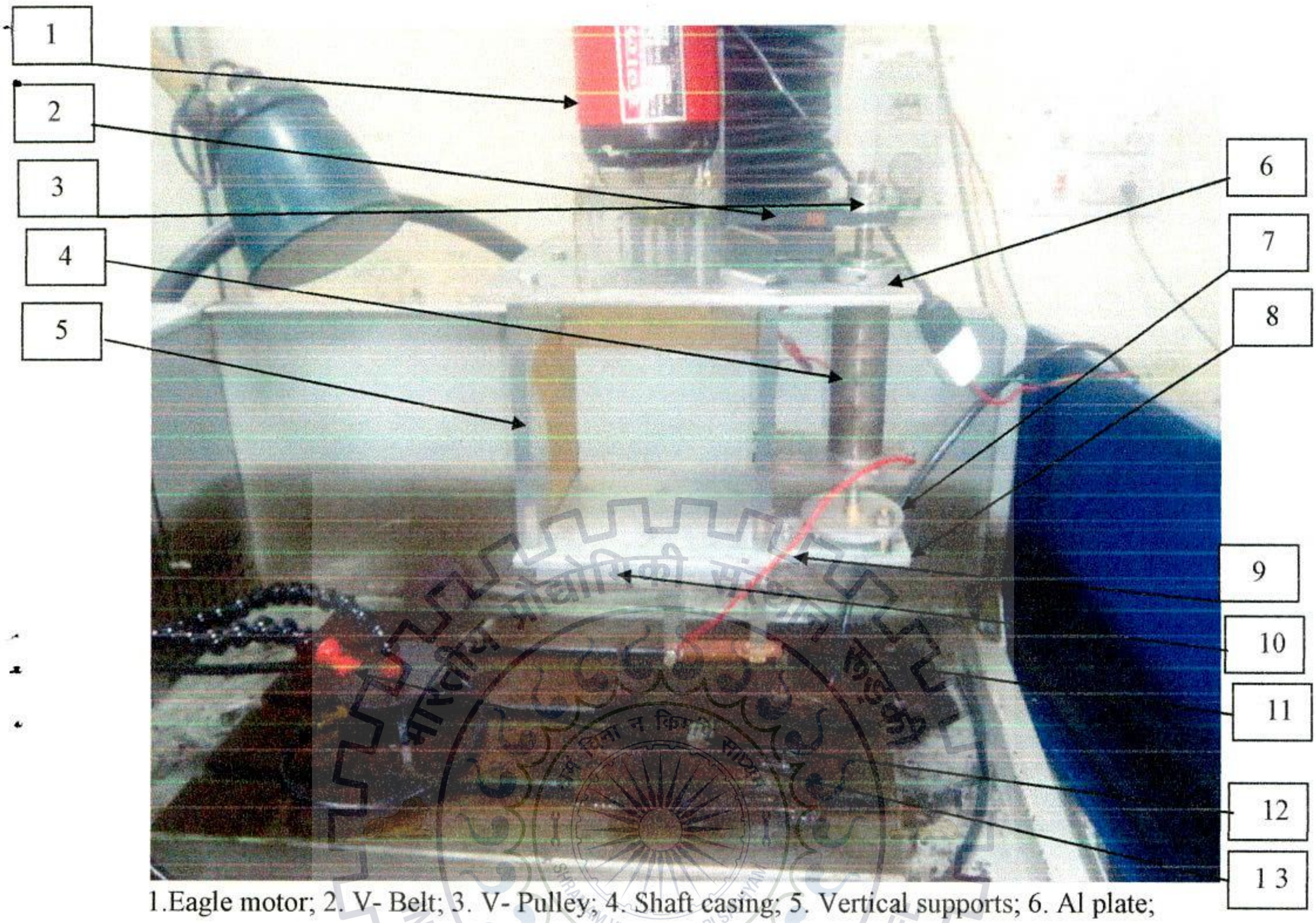


Figure 25: Production drawing and actual view of tool holder.

Table 12: Different operations used in production of tool holder

Operation no	Operation	Machine Tool	Tool used
1.	Marking	-	Scale and marker
2.	Cutting	Shaper Machine	Single point cutting tool
3.	Drilling	Drilling Machine	Drill bit
4.	Internal threading	AdjusTable tap handle	Tap
5.	Finishing	Bench filing	Amber paper and filing
6.	Inspection	-	Vernier scale

5.3.14 Complete Assembly of Setup



1.Eagle motor; 2. V- Belt; 3. V- Pulley; 4. Shaft casing; 5. Vertical supports; 6. Al plate;

7. Disc; 8. Sliding yoke; 9. Sliding bar; 10. Guideways; 11. Cu tool; 12. Workpiece;

13. Nozzle

Figure 26: Actual view of the EDS setup

CHAPTER 6 RESULTS AND DISSCUSSIONS

6.1. Experimental procedure

6.1.1. Materials and methods

In this experiment, Al6063-SiC metal matrix composite (MMC) is used as a work piece material. The reinforcement material is silicon carbide and matrix material is aluminium-6063. The chemical composition of the workpiece material is 90% aluminium and 10% SiC. The MMC was prepared by using stir casting process. The schematic of the stir casting setup is shown in Figure 27. A stainless steel crucible is used in a muffle furnace with argon atmosphere. Rods of matrix material were placed in the crucible and heated to 730˚C until the material melted completely. 2% Mg by weight was added at 650˚C to improve the wettability. Preheated particles of SiC were added to the melt at a uniform rate with argon gas as a media. Stirring was provided for five minutes to mix all the reinforcement particles completely in the melted matrix material. After stirring, the mixture was squeezed for one minute under the pressure of 20 MPa. The crucible was taken out and water quenched. The workpiece was made in the form of a rectangular plate of dimension 100 mm$\times 50mm \times 20mm$.

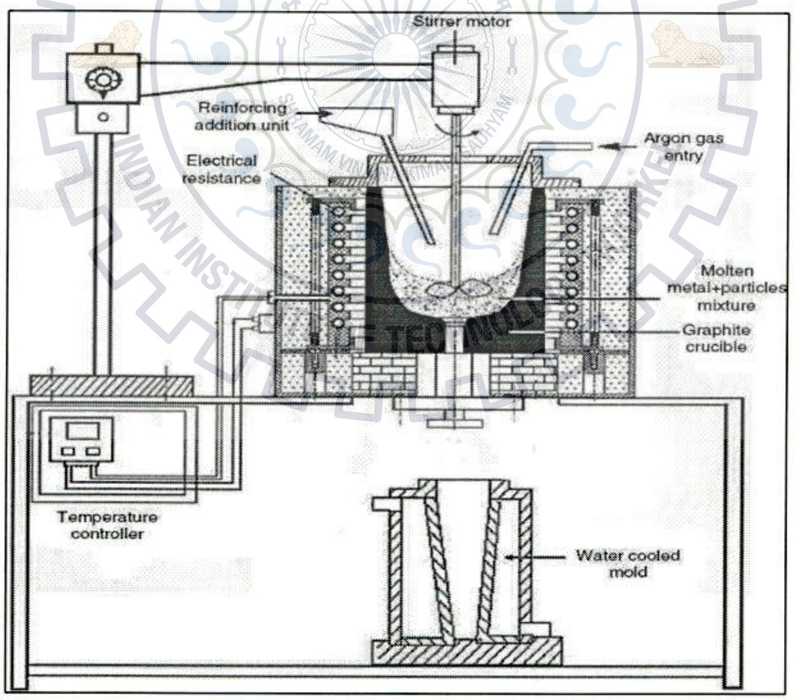


Figure 27: Schematic diagram of stir casting process[23]

6.1.2 Experimentation

Thirty experiments were conducted by using one- factor- at–a-time approach. The range of current, pulse on time, pulse of time, gap voltage, lift, stroke length and RPM were selected on the basis of literature and all other parameters were kept constant as shown in Table 13.

Table 13: Machining parameters

Current (A)	3,4.5,6,9
T_{on} (us)	90,120,150.200,300
T_{off} (us)	2,3,4,5,6
Gap voltage (v)	40,45,50,60
Lift	2,3,4,5,6
Stroke length (mm)	30,40,50
Disc (crank) speed (RPM)	220,280.400,480
Other parameters (constant): Spark 4, polarity positive	

The values are fed into the controller of the machine. The speed of the motor was measured by laser tachometer. A depth of 20 mm was programmed for the tool to penetrate down after its first electrical contact with the work piece. MRR and TWR were calculated for each experiment. MRR is expressed as the ratio of the difference of weight of work piece before and after machining to the machining time.

$$MRR\ (mm^3/min) = \frac{1\times10^6 * weight\ loss}{Machining\ time * Density} \quad [1]$$

In equation 1, weight loss in grams, machining time in minutes, density in kg/m^3.

6.1.3 Results and discussion

EDS as a non conventional machining method gives better results than conventional machining methods undoubtedly. Though the initial cost is higher, but that is compensated by better results. After performing the experiments on MMC, it is found that the reciprocating motion of the tool provides additional flushing to the process. When a workpiece with a greater depth is machined from stationary tool, then the injection flushing becomes less effective to remove the debris from the machine zone. When reciprocating motion is given to the tool, the spark advances from one point to another which takes away the carbon particles with it and results in lower machining time and increases the material removal rate. Figure 28 shows the machined MMC.

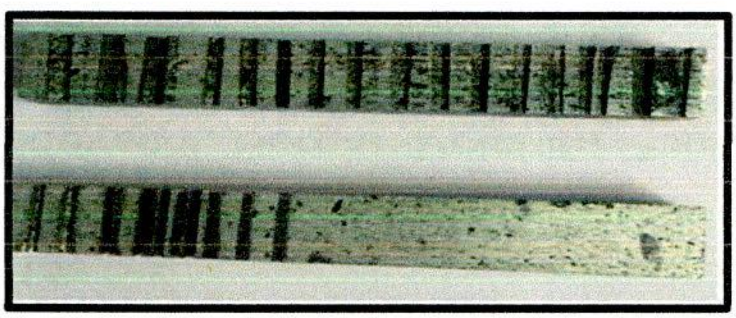


Figure 28: Machined Workpiece

Table 14: Experimental data for MRR, TWR for EDS for MMC's

Sr. No.	Current (A)	pulse on time	off time	Gap voltage (V)	Lift	Stroke length (mm)	Speed(RPM)	MRR	TWR
1	3	150	3	45	3	30	220	2.09	0.05859375
2	4.5	150	3	45	3	30	220	6.11	0.077008929
3	6	150	3	45	3	30	220	7.78	0.078125
4	9	150	3	45	3	30	220	12.77	0.085565476
5	6	90	3	45	3	30	220	2.56	0.180803571
6	6	120	3	45	3	30	220	3.79	0.102678571
7	6	150	3	45	3	30	220	7.63	0.125
8	6	200	3	45	3	30	220	6.59	0.073660714
9	6	300	3	45	3	30	220	8.00	0.033482143
10	6	150	2	45	3	30	220	1.49	0.138392857
11	6	150	3	45	3	30	220	4.84	0.180803571
12	6	150	4	45	3	30	220	8.99	0.113839286
13	6	150	5	45	3	30	220	7.96	0.1875
14	6	150	6	45	3	30	220	7.36	0.37202381
15	6	150	4	40	3	30	220	5.13	0.216517857
16	6	150	4	45	3	30	220	4.30	0.1875
17	6	150	4	50	3	30	220	3.90	0.125
18	6	150	4	60	3	30	220	0.97	0.113839286
19	6	150	4	50	2	30	220	3.50	0.229910714
20	6	150	4	50	3	30	220	6.07	0.102678571
21	6	150	4	50	4	30	220	2.55	0.104910714
22	6	150	4	50	5	30	220	2.56	0.073660714
23	6	150	4	50	6	30	220	1.73	0.09375
24	6	150	4	50	3	30	220	5.61	0.118303571
25	6	150	4	50	3	40	220	2.81	0.113839286
26	6	150	4	50	3	50	220	2.53	0.080357143
27	6	150	4	50	3	30	220	3.69	0.040178571
28	6	150	4	50	3	30	280	2.47	0.065848214
29	6	150	4	50	3	30	400	7.93	0.073660714
30	6	150	4	50	3	30	470	6.66	0.0189

6.1.3.1. Effect of current on MRR and TWR

The Figure 29 shows the result obtained when current was varied with the values of pulse on time, pulse off time, gap voltage, lift, stroke length, and RPM as 150, 3, 45, 3, 30 and 220 respectively.

It was found from the results that increasing the value of current lowers the machining time and hence increases the material removal rate. It is due to the fact that as we increases the current we supply more electrical energy we get more work in terms of material removal rate in the similar manner tool wear rate also increases as we increase the value of current.

Further experimentations were carried out at 6 A current level. At this level of current, MRR and TWR were obtained satisfactory and surface quality was also better than 9 A current.

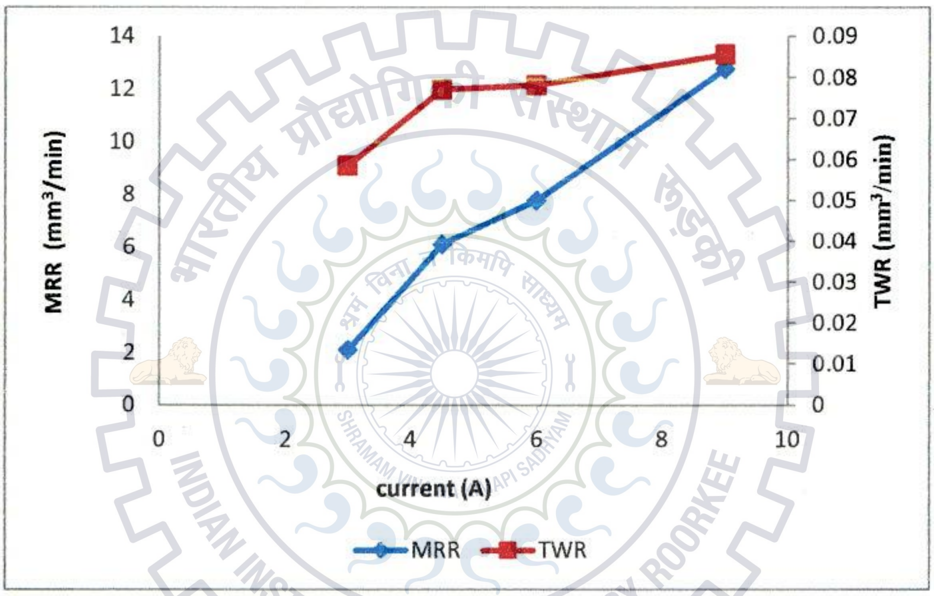


Figure 29: Effect of current on MRR and TWR

6.1.3.2. Effect of pulse on time on MRR and TWR

The Figure 30 shows the results obtained when pulse on time was varied with the values of current, pulse off time, gap voltage, lift, stroke length, and RPM as 6, 3, 45, 3, 30 and 220 respectively.

It is clearly visible from the graph that as we increases the pulse on time, firstly there is an increase in MRR, then it remains almost constant and further increase in pulse on time results in an increase in MRR further this can be justified with the fact that as pulse on time increases sparking time increase, longer pulse duration releases more energy at the workpiece leading to higher MRR. But it also leads to large craters on the workpiece surface and sometimes pits are also observed. A pit appears where the SiC particles have been removed in bulk.

Further experimentations were carried out at 150 pulse on time. At this level of pulse on time, MRR and TWR were obtained satisfactory and surface quality was also better than 200 pulse on time.

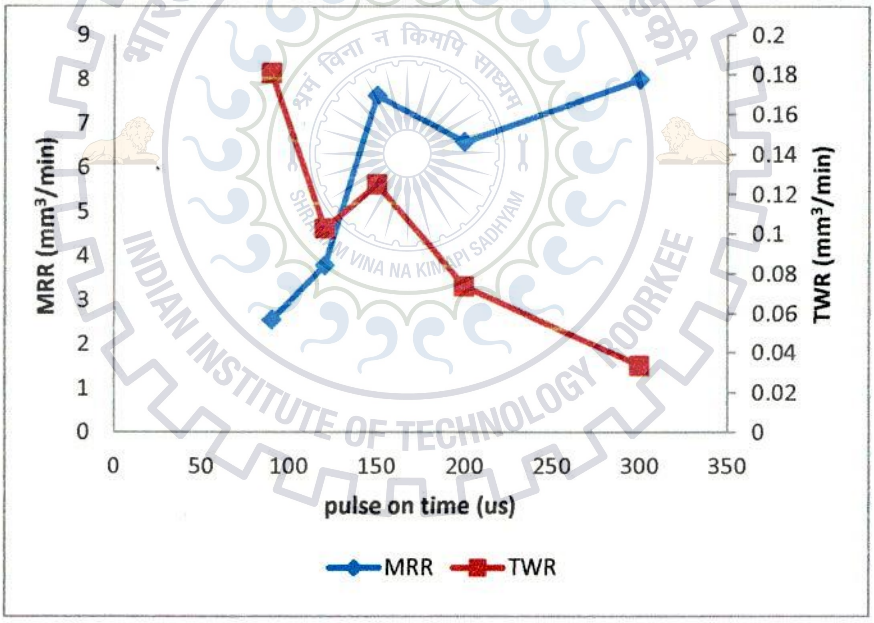


Figure 30: Effect of pulse on time on MRR and TWR

6.1.3.3. Effect of pulse off time on MRR and TWR

The Figure 31 shows the result obtained when pulse off time was varied with the values of current, pulse on time, gap voltage, lift, stroke length, and RPM as 6, 150, 45, 3, 30 and 220 respectively.

It is clear from the graph that as we increase pulse off time, firstly MRR increases, then after an optimum value it goes on decreasing. This is due to the fact that firstly as pulse off time is very less than proper flushing is not obtained so MRR is very less but as we increase the pulse off time we get proper flushing which enhances the MRR but after a particular value as pulse off, time further increase tool gets cool down and in the cycle unproductive time increases which results in a decrease in MRR.

Further experimentations were carried out at 4 pulse off level. At this level of pulse of time, MRR obtained is maximum and TWR were obtained satisfactory and surface quality was also better than 5 and 6 pulse of time.

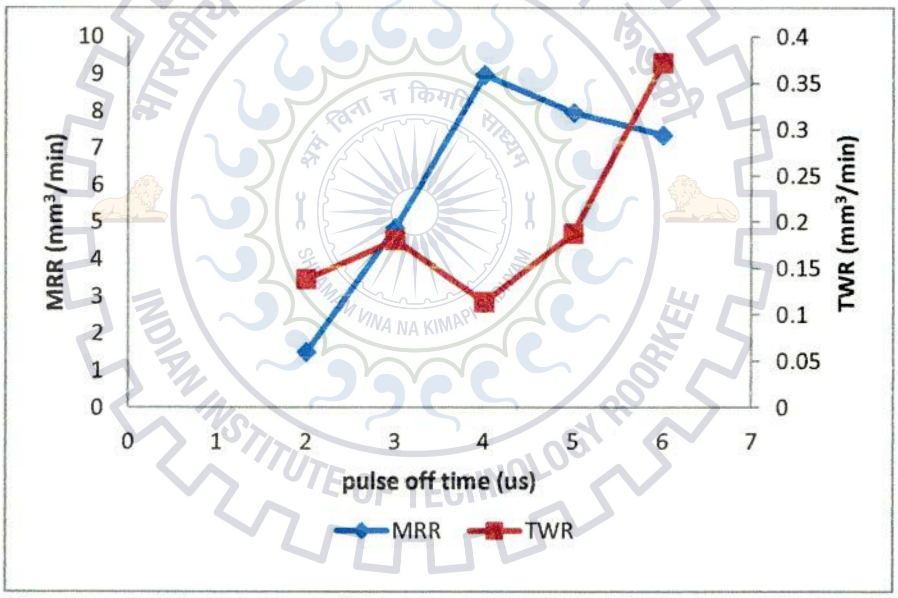


Figure 31: Effect of pulse off time on MRR and TWR

6.1.3.4. Effect of gap voltage on MRR and TWR

The Figure 32 shows the result obtained when gap voltage was varied with the values of current, pulse on time, pulse off time, lift, stroke length, and RPM as 6, 150, 3, 3, 30 and 220 respectively.

It is clear from the graph that as we increase the gap voltage, firstly MRR increase then it continuously decreases this is due to the fact that an inter electrode gap changes frequently so proper sparking is not obtained during the machining operation. Another reason of decreasing MRR with the increase in gap voltage is due to the uneven surface of tool which creates an obstacle to find a proper inter electrode gap. Another reason may be vibration present in the setup may result in reverse effects of gap voltage with MRR.

Further experimentations were carried out at 50 V gap voltage level. At this level of gap voltage, MRR and TWR were obtained satisfactory and surface quality was also better than 60 gap voltage level.

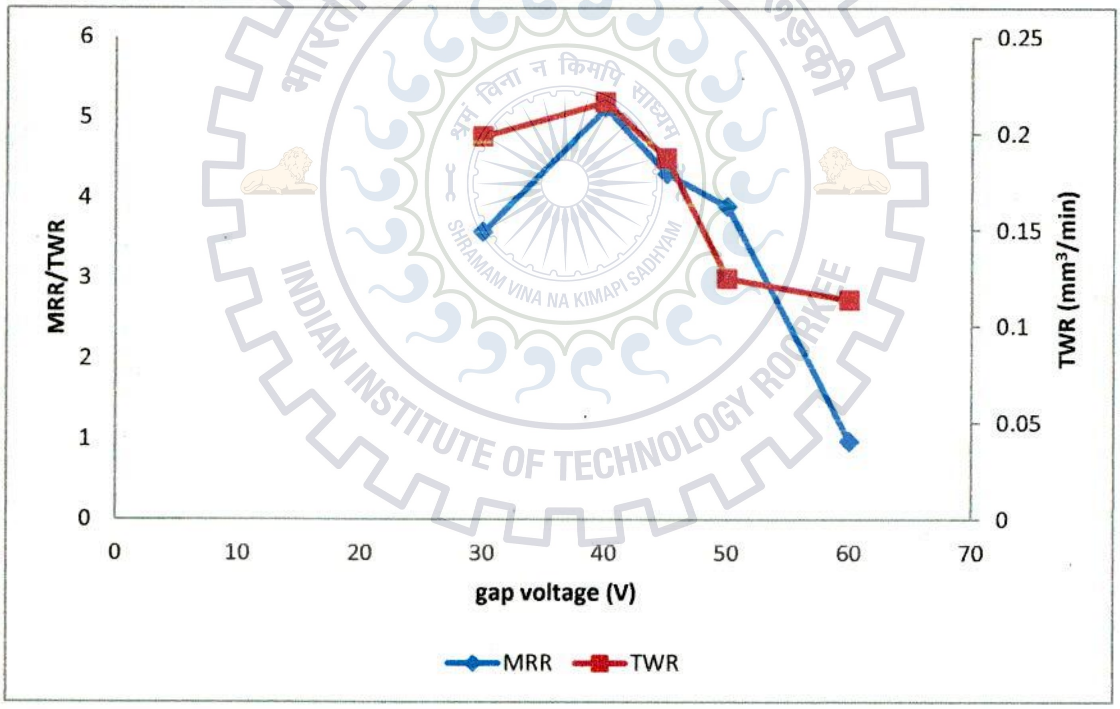


Figure 32: Effect of gap voltage on MRR and TWR

6.1.3.5. Effect of lift on MRR and TWR

The Figure 33 shows the results obtained when Lift was varied with the values of current, pulse on time, pulse off time, Gap Voltage, stroke length, and RPM as 6, 150, 3, 50, 30 and 220 respectively.

It is clear from the graph that as we increase the lift, firstly MRR increases, but after a particular value it starts decreasing. This is due to the fact that firstly lift is very less so effective flushing is not obtained, but as lift increases proper gap between tool and workpiece is obtained which provides adequate space to wash away the debris. Therefore, MRR increases, but as we further increase the lift tool gets cooled down so it enhances the cutting time which ultimately results in decrease of MRR. Further, as lift increases, unproductive time in cycle increase, which results in a decrease of MRR. Similar results are obtained for TWR also. Further experimentations were carried out at 3 lift level. At this level of lift, MRR obtained is maximum and TWR were obtained satisfactory.

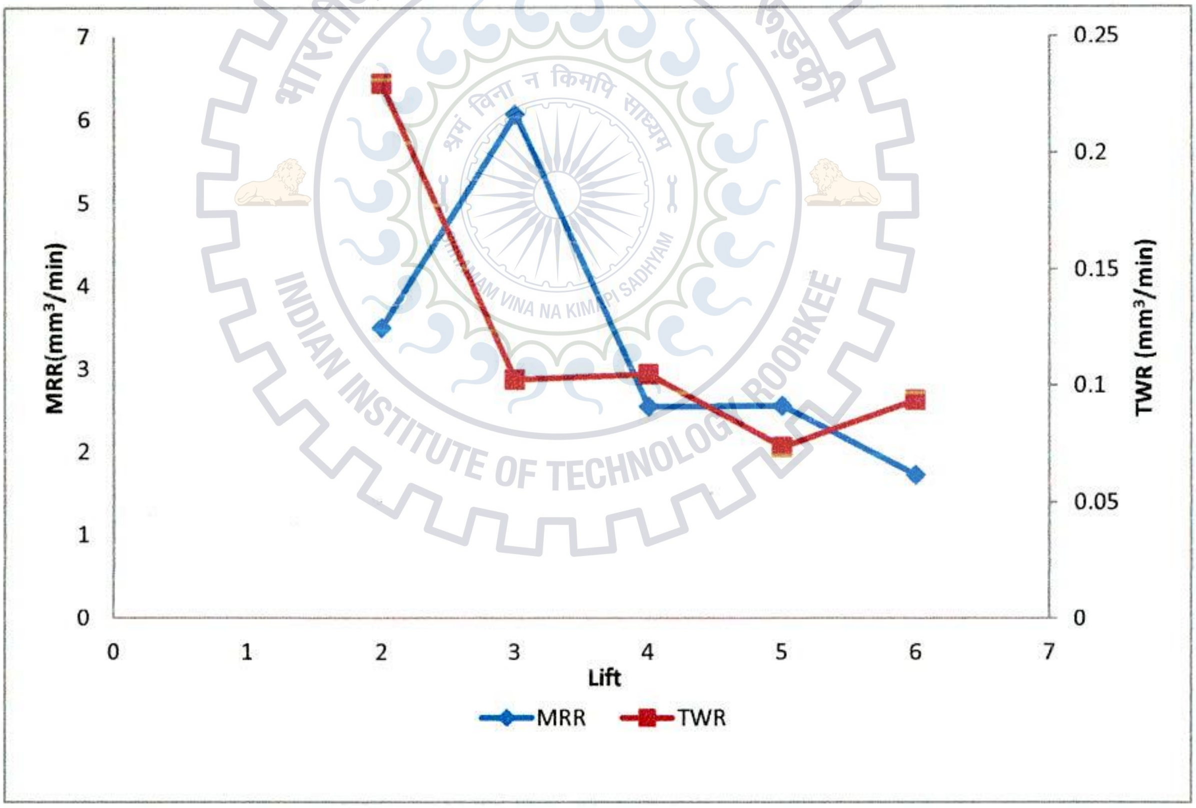


Figure 33: Effect of lift on MRR and TWR

6.1.3.5. Effect of stroke length on MRR and TWR

The Figure 34 shows the result obtained when Stroke Length was varied with the values of current, pulse on time, pulse off time, Gap Voltage, Lift, and RPM as 6, 150, 3, 50, 3 and 220 respectively.

It is clear from the graph that as stroke length increases MRR decreases gradually. This is due to fact that as stroke length increase, the tool has to cover more distance as compared to the shorter stroke length so tool remains less time with the work piece which ultimately results in less MRR. Another reason may be waviness of the tool due to which it touches un-wanted locations which results in TWR at a faster rate and MRR decrease because cutting is not at the desired location. Further, there may be manufacturing defects (i.e. This may result in vibrations) in the setup causing inaccuracy in machining which ultimately results in low MRR and high TWR. Further experimentations were carried out at stroke length of 30 mm level. At this level of stroke length, MRR obtained is maximum and TWR were obtained satisfactory.

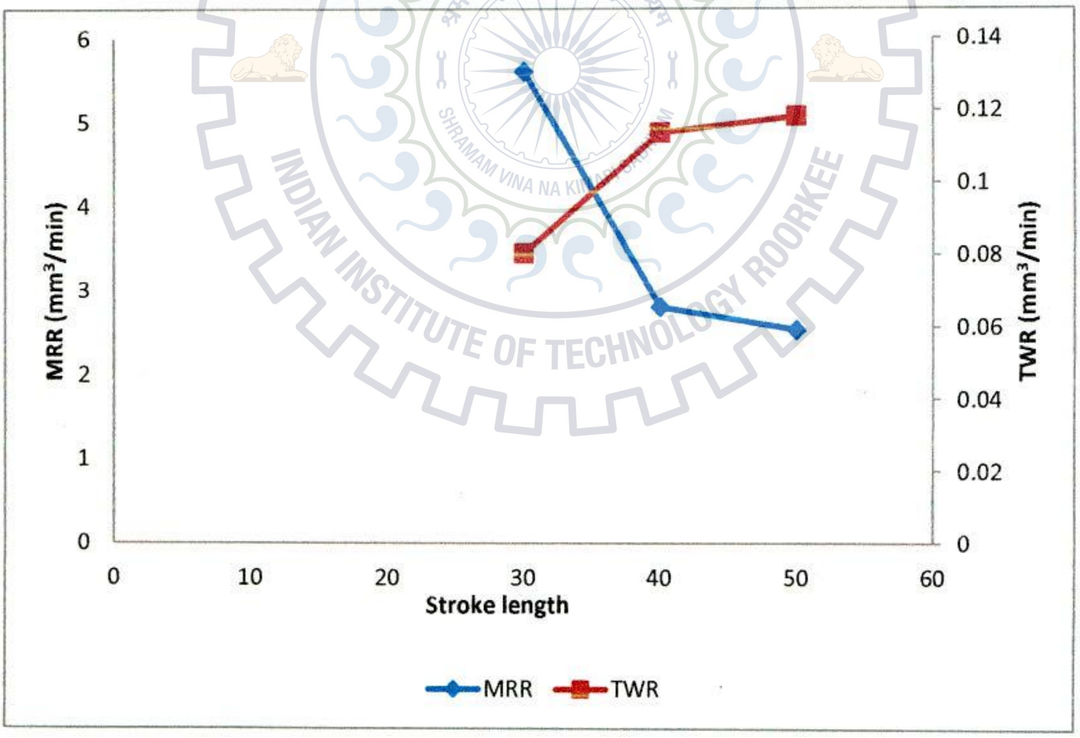


Figure 34: Effect of stroke length on MRR and TWR

6.1.3.5. Effect of RPM on MRR and TWR:

The Figure 35 shows the result obtained when RPM was varied with the values of current, pulse on time, pulse off time, gap voltage, Lift, and stroke length as 6, 150, 3, 50, 3 and 30 respectively. It is clear from the graph that as RPM increases firstly MRR and TWR increase and after a particular optimum value, MRR decreases. This is due to the fact that in our case MRR depends on flushing efficiency and proper sparking time. These two factors are responsible for MRR. As we increase rotational speed, it enhances the flushing which increases MRR but after a particular speed, MRR decreases due to improper sparking time which result in less sparking ultimately less MRR. Similar results are obtained for TWR also.

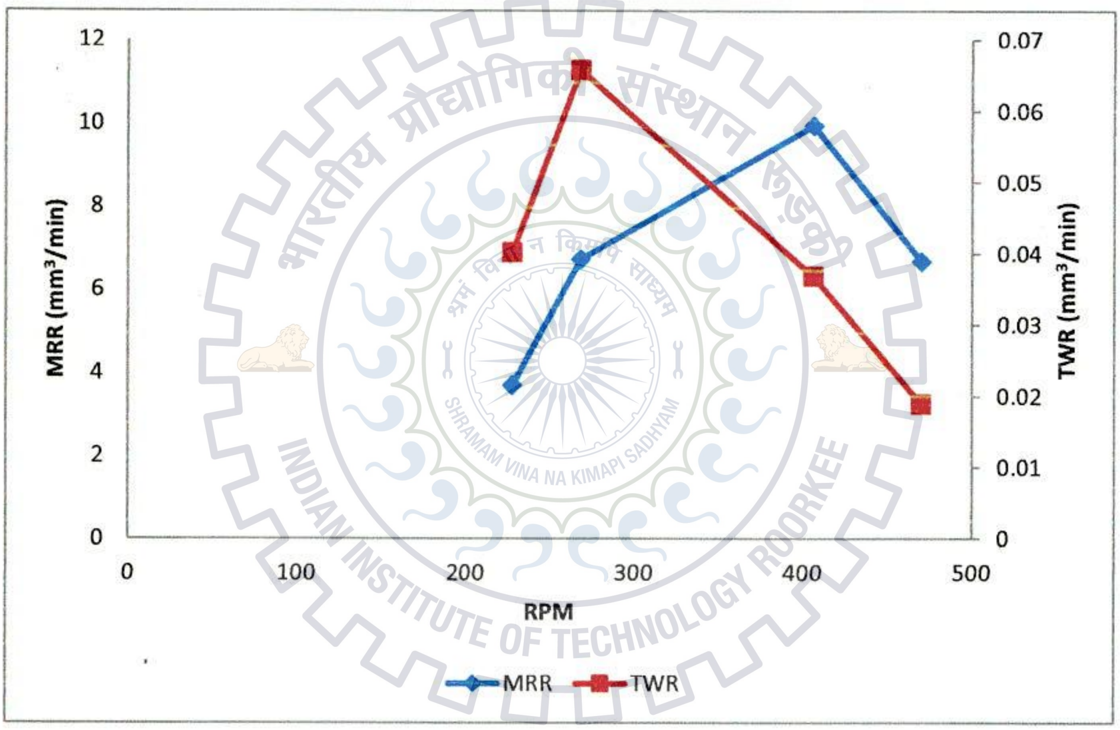


Figure 35: Effect of RPM on MRR and TWR

CONCLUDING REMARKS

The introduction of EDM to the metal cutting has been a viable machining option for manufacturing extremely complicated parts, independent of the mechanical properties of workpiece material. This can be by virtue of the potential of EDM to economically machine elements, which are tough to be carried out by conventional material removal processes. With continuous improvement within the metal removal efficiency and also the incorporation of numerical control, the viability of the EDM process in terms of the kind of applications is significantly extended. The basis of the EDM process principally depends on empirical methods mostly attribuTable to the stochastic nature of the sparking development involving each electrical and non-electrical process parameters. The complicated interrelationship between the various optimized process parameters is thus a significant issue contributing to the machining efficiency. However, several means of improving the machining performance commonly measured in terms of MRR, TWR and SR are created with an amazing research interest been paid to the metallurgic properties of EDMed part. Thus, the EDM method has to be constantly revived to stay competitive in providing a vital and valuable role within the tool space manufacturing of part with difficult-to-machine materials and geometries.

From the present experimental investigation, the following conclusions can be drawn;

a) EDS (electrical discharge sawing) set-up is feasible for machining of MMC's.

b) The MRR achieved with the developed set-up is higher as compared to the conventional WEDM process.

c) A higher setting of current leads to higher MRR.

d) The optimum value of pulse on time is obtained which leads to maximum MRR and lower TWR.

e) Similarly, the optimum value of pulse off time is obtained which leads to maximum MRR and lower TWR.

f) Experiments also performed by varying the rotational speed and effects on MRR and TWR are obtained. An optimum value of rotational speed is obtained which gives highest MRR.

The feasibility of the developed set-up can be investigated for machining of other hard to machine materials, such as titanium, Inconel, die steel, tool steel. These days there is huge demand of MMC shaft's in automobile industry. EDS may be an effective way to cut keyways and other operation in MMC shafts.

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