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Experimental Investigations on Powder Mixed Electric Discharge Machining

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Abstract: **The development of super tough electrical conductive materials such as carbides, stainless steels, hastalloy, nitralloy, nomonics, etc., risen the requirement of non-traditional manufacturing processes. These materials are very difficult to machine by conventional methods. These materials finds applications in industry where high strength to weight ratio and hardness. Electric Discharge Machining (EDM) is one of the most extensively used non conventional machining processes. It uses thermal energy to machine all electrical conductive materials of any toughness and hardness for manufacturing of dies, aerospace parts. Since there is no direct contact between work piece and tool electrode in EDM. In spite of remarkable advantages of the process, disadvantages like poor surface finish an low Material Removal Rate (MRR) limits its use in industry. In past few years powder mixed Electric Discharge Machining (PMEDM) emerges a new technique to enhance process capabilities. So in this study, an attempt has been made to study the effect of copper powder mixed in the dielectric fluid of Electric Discharge Machining on the machining characteristics of High Carbon High Chromium (H.C.H.Cr) steel. Concentration of Powder and Current are taken as the parameters to measure process performance. The Experimental investigations are carried out using copper electrode. Experiments are done in developed EDM setup. The study indicates that both the input parameters strongly affect the machining performance of H.C.H.Cr steel. The addition of copper powder in dielectric medium increases MRR and decreases surface finish.**

Keywords: Electric Discharge Machining, PMEDM, High Carbon High Chromium steel, copper electrode

I..INTRODUCTION

Electric Discharge Machining (EDM):

Electric Discharge Machining is one of the earliest unconventional machining processes. In 1770 English scientist Joseph Priestly firstly invented the erosive effect of electrical discharge machining. 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. It is commercially developed in the mid 1970s, wire EDM began to be a viable technique that helped shape the metal working industry we see today. In the mid 1980s.The EDM techniques were transferred to a machine tool. This migration made EDM more widely available and appealing over conventional machining processes.

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 materials that are difficult to machine like, tool steels, tungsten carbides etc.
3. It is used for making forging, extrusion, wire drawing and thread cutting dies.
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 machining. Hence areas that require higher surface accuracy use the EDM machining process.
8. Ceramic materials that are difficult to machine can be machined by the EDM machining process.
9. Electric Discharge Machining has also made its presence felt in the new fields such as sports, medical and surgical, instruments, optical, including automotive R&D areas.
10. It is a promising technique to meet increasing demands for smaller components usually highly complicated, multi-functional parts used in the field of micro-electronics.

Working principle of EDM:

Electro Discharge Machining (EDM) is an electro-thermal unconventional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark. EDM is mainly used to machine difficult-to-machine 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. The working principle of

EDM process is based on the thermoelectric energy. This energy is created between a work piece and an electrode submerged in a dielectric fluid with the passage of electric current. The work piece and the electrode are separated by a specific small gap called spark gap. Pulsed arc discharges occur in this gap. The electrode moves toward the work piece reducing the spark gap so that the applied voltage is high enough to ionize the dielectric fluid. Short duration discharges are generated in a liquid dielectric gap, which separates electrode and work piece. The material is removed from tool and work piece with the erosive effect of the electrical discharges. The dielectric fluid serves the purpose to concentrate the discharge energy into a channel of very small cross sectional areas. It also cools the two electrodes, and flushes away the products of machining from the gap. The electrical resistance of the dielectric influences the discharge energy and the time of spark initiation. Low resistance results in early discharge. If resistance is large, the capacitor will attain a higher charge value before initiation of discharge. A servo system is employed which compares the gap voltage with a reference value and to ensure that the electrode moves at a proper rate to maintain the right spark gap, and also to retract the electrode if short circuiting occurs. When the measured average gap voltage is higher than that of the servo reference voltage, preset by the operator, the feed speed increases.

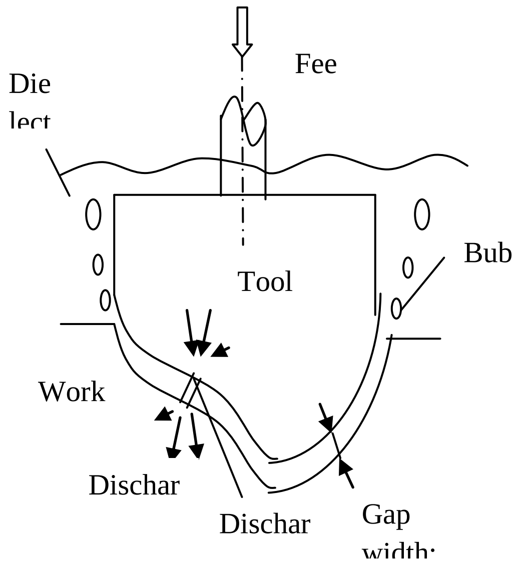


Figure 1: Working principle of EDM

Basic EDM process parameters:

The Process parameters can be divided into different categories i.e. electrical, non-electrical Parameters, electrode parameters, powder parameters

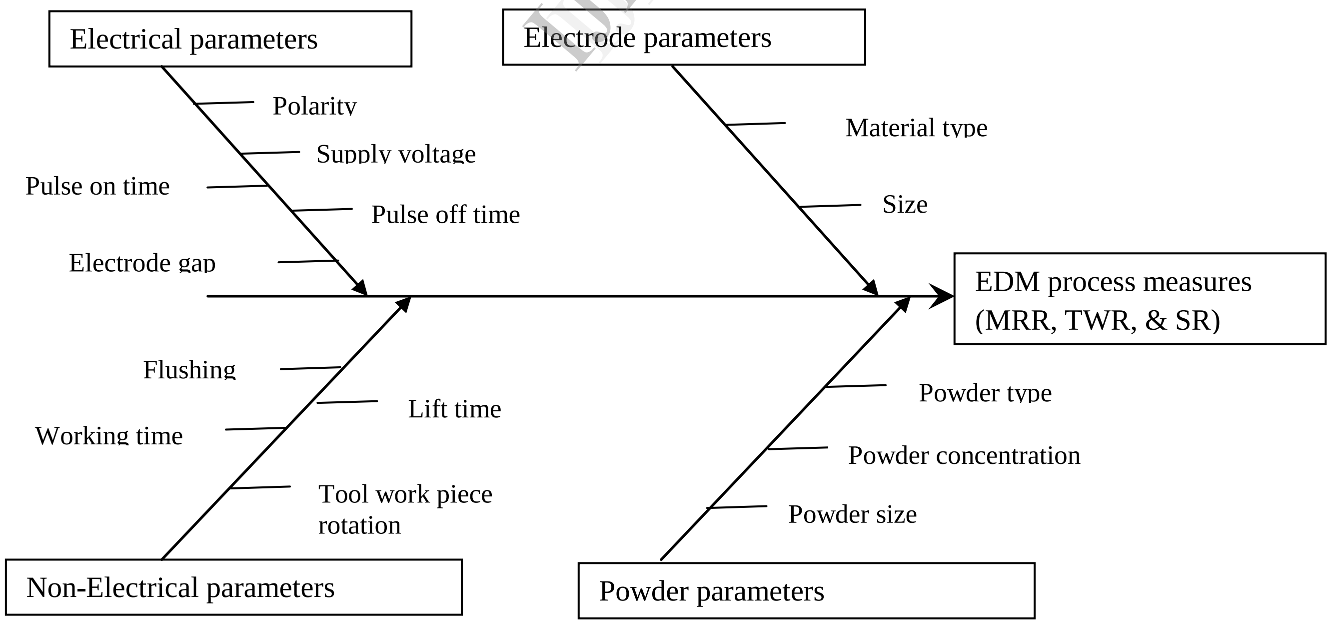


Fig 1.2: EDM process parameters

Advantages of EDM:

- The process can be used to machine any work material and tool material if it is electrically conductive
- Material removal depends on mainly thermal properties of the work material rather than its strength, hardness etc
- In EDM there is a physical tool and geometry of the tool is the positive impression of the hole or geometric feature machined
- Though the local temperature rise is rather high, still due to very small pulse on time, there is not enough time for the heat to diffuse and thus almost no increase in bulk temperature takes place. Thus the heat affected zone is limited to 2 – 4 μm of the spark crater.
- However rapid heating and cooling and local high temperature leads to surface hardening which may be desirable in some applications
- Though there is a possibility of taper cut and overcut in EDM, they can be controlled and compensated.

Complex dies sections and moulds can be produced accurately, faster, and at lower costs. Due to the modern NC control systems on die sinking machines, even more complicated work pieces can be machined..

Limitations of EDM:

(a) The need for electrical conductivity – To be able to create discharges, the work piece has to be electrically conductive. Isolators, like plastics, glass and most ceramics, cannot 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 a deviation of the desired work piece geometry and it could reduce the achievable accuracy. Intermediate measuring of the work piece or some preliminary 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.

II. LITERATURE REVIEW

Kunieda *et al* [1] reports that compared to other discharge phenomena such as glow discharge in dry etching processes and arc discharge in welding processes, physics involved in EDM processes are obviously most complicated, rendering observation and theoretical analysis extremely difficult. Zhao et al [2] conducted experiments by varying peak current and pulse width and observed that machining efficiency is increased in both cases surface roughness increase to certain extent and there by decreased. Kansal et al. [3] reports the efficiency of the EDM depends on the thermo physical properties of powder, concentration, particle size and density. Kansal et al [4] observes when powder is mixed in dielectric medium the interlocking between different powders particles will occur in direction of flow of current. The chain formation helps in bridging. Due to bridging effect the insulating strength of dielectric fluid decreases As a result ‘series discharges’ starts under the electrode area. The faster sparking with in a discharge taken place causing faster erosion from the work piece surface and hence MRR increases. Huang et al.[5[found that introduction of ultrasonic vibration on the tool electrode in micro-EDM has increased the machining efficiency more than 60 times. Without significantly improving the electrode wear. They also found that efficiency improvement is attributed to the strong stirring effect caused by ultrasonic effect, which results in excellent flushing in the micro-EDM processes. At low frequency level which is below 1000 Hz. Wong et al.[6] reported that machining done by positive electrode give rise to high material removal with deep craters that do not overlap evenly leads to high roughness value where as machining done by negative electrode gives rise to low material removal rate due to shallow craters results in smooth surface. Prihandana et al.[7] reported that ultrasonic vibration of dielectric fluid is significant in increasing the material removal rate. It reduces adhesion of debris and prevents the micro powder from being deposited at the bottom of the tank providing a better distribution of powder to sparking gap results in more powder to flow between the tool electrode and work piece, as it no longer accumulates at the bottom of the tank, to support the machine process and increases the material removal rate. Singh et al. [8] reported that too low and too high (concentration, grain size) of Aluminum powder reduces MRR. Singh et al.[9] reported the addition of Aluminum powder in EDM oil results in appreciable reduction in surface roughness of Hastelloy when machined with copper electrode. G. S Prihandana et al., [10] reported that presence of micro MoS_2 powder in the dielectric fluid effects the distribution of current paths over the surface to produce a flat surface free of black spots in center. In addition the high lubricity of MoS_2 also helped to improve the surface quality. Furthermore he observed that smallest particle generates the best surface finish and greater the particle size, the worse the surface roughness. It is due to small particle producing fine machining effects.

III. DEVELOPMENT OF POWDER MIXED EDM SET UP:

The EDM set up consists of the stepper motor coupled with micrometer for tool feed was developed for conducting PMEDM studies.

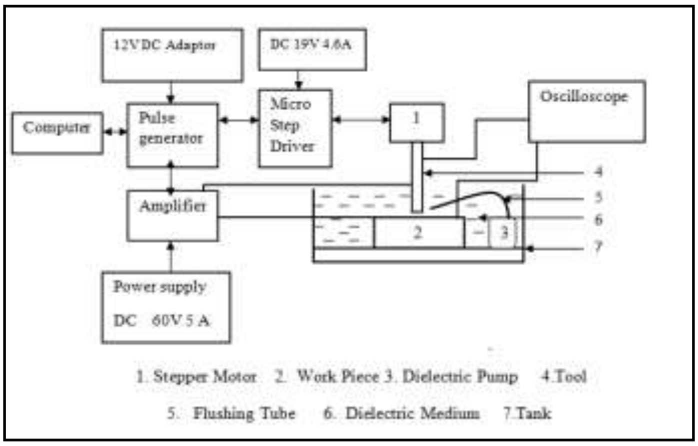


Fig 3.1 Schematic of EDM set up

Stepper motor A stepper motor is a brushless, synchronous electric motor that converts digital pulses into mechanical shaft rotation shown in Fig 3.2. Every revolution of the stepper motor is divided into a discrete number of steps, in many cases 200 steps, and the motor must be sent a separate pulse for each step.

Fig 3.2: Hybrid stepper motor

Table 3.1 Specifications of the hybrid stepper motor

Holding Torque (Kg-cm)	3.2
Current	0.8
Resistance	10
Detent Torque	150
Rotor Inertia (g-cm^2)	57
Weight (Kg)	0.24
Length(mm)	40
Shaft Diameter (mm)	5
Step angle	1.8°

Micro-step Driver

Micro stepping is a relatively new stepper motor technology that controls the current in the motor winding to a degree that further subdivides the number of positions between poles. Micro stepping drives are capable of dividing a full step (1.8º) into 64 micro steps, resulting in 12800 steps per revolution (0.028º/step)

Table 3.2 Specifications of Micro-step driver

Parameter	Minimum	Typical	Maximum
Output current (Amps)	0.21	-	1.5
Supply Voltage (V)	15	36	40
Input Current (mA)	7	10	16
Pulse Input Fequency (KHz)	0	-	200

Powersupply:

Power supply is the important source in EDM which converts electrical energy to thermal energy and connected between electrode and work piece. Pulsed Direct Current (DC) is powered in EDM. DC Regulated power supply is used in EDM set up as shown in Figure 3.3.

Fig 3.3 DC Regulated power supply

Micrometer

In EDM setup micro meter is a device which converts rotary motion to mechanical motion. The photograph is shown in Figure 3.4

Fig 3.4 Photograph of micrometer

Oscilloscope :

Oscilloscope is used to observe the exact wave shape of an electrical signal during machining. It is calibrated so that voltage and time can be read by the eye. This allows the measurement of peak-to-peak voltage of a waveform, the frequency of periodic signals, the time between pulses.

Fig 3.5 Photograph of Oscilloscope

Dielectric tank:

Volume of tank is 190 x100 mm (Radius x height) i.e 2.88 liters, made of Borosil. Fig 3.6

Fig.3.6 Photograph of Dielectric tank

Submersible Pump:

Pump is placed in the dielectric tank for re-circulating and flushing the dielectric medium.

Digital Pulse generator Pulse width modulation PWM is the technique used to generate analogue signals from a digital device like a MCU. Almost all modern MCUs have dedicated hardware for PWM signal generation. In present study TIMER0 (TCCR0, TCCR02) are used for PWM generation. In simple term TIMER is a 8-bit register.

Explanation of Controlling components on GUI:

ADC value: Resistance bridge is used to step down the voltage from 60V to 5V. The output of Resistance bridge is connected to the ADC pin of controller. The analog value is converted to 8-bit digital value. This ADC value is conversion of supplied voltage 0-60V to digital 8 bit number 0-255.This value is also used for debugging the machine functioning.

ADC value	Mode	Tool motion
0-80	Tool and work piece are in contact	Moves back ward
81-190	During sparking	Stops moving down
191-253	Large gap between tool and work piece	Starts moving down

Table 3.4 Relation between tool motion and ADC Value

Duty Cycle: A duty cycle is the percent of time that an entity spends in an active state as a fraction of the total time under consideration. The suitable number in the computer is to be given to change the duty cycle of the pulse as shown in Table 3.5

Duty cycle control		Tool direction control	
Input value	Obtained Duty cycle	Input number	Direction
64	25%	0	Reverse
128	50%	1	Forward
192	75%	-	-

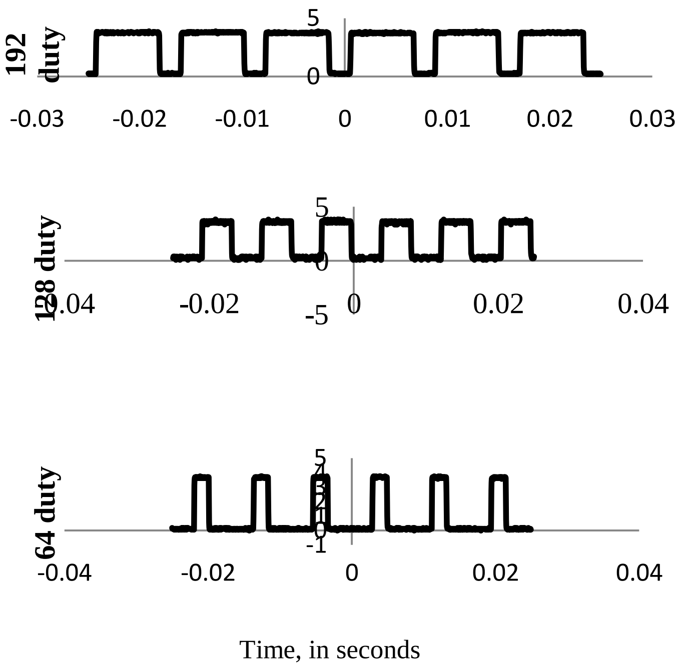


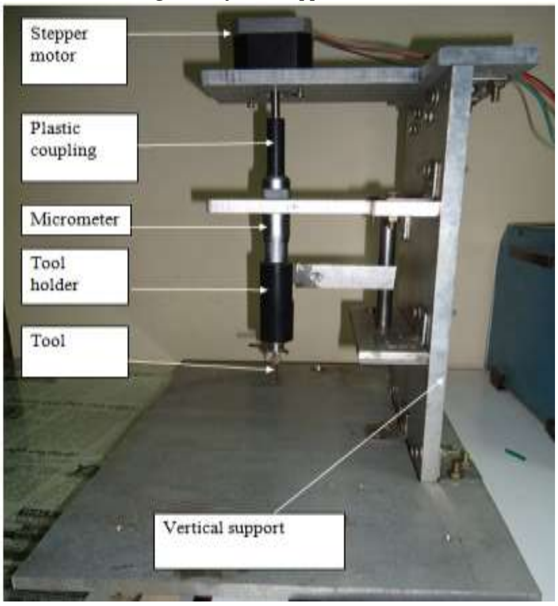
Fig 3.7: Pulse trains of (25-75% duty ycle)

Final assembled EDM set up: Physical support for tool movement is made of aluminum plate with thickness 10 mm, in order to ensure the rigidity of structure. The assembled set up is shown in figure 3.10.

Fig 3.8: Photograph of different components used for Physical support of EDM setup

Figure 3.9 shows the different components used to make a physical support for tool movement. This physical support combined with micro controller and personnel computer makes the complete PMEDM set up as shown in figure 3.10, which is used for conducting experiments by mixing copper powder in dielectric medium.

Fig 3.9 Physical support for tool



IV .POWDER MIXED ELECTRIC DISCHARGE MACHINING

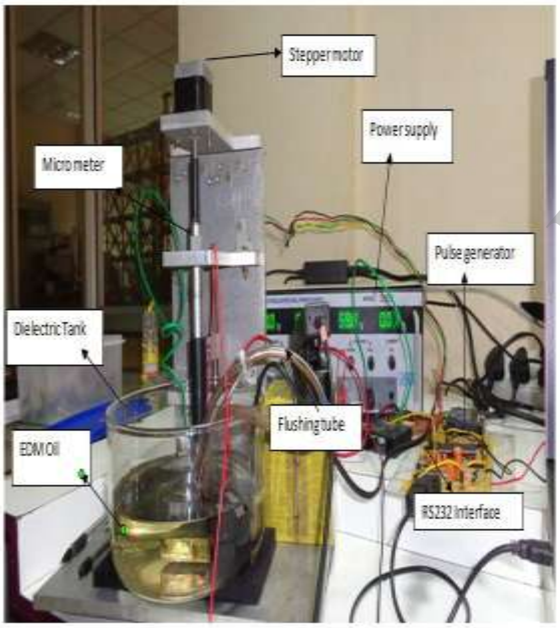


Fig.3.10P Final assembled set up

Introduction: PMEDM is one of the new innovations for the enhancement of capabilities of electric discharge machining process. In this process, a suitable material in fine powder is properly mixed into the dielectric fluid. The added powder improves the breakdown characteristics of the dielectric fluid. The insulating strength of the dielectric fluid decreases and as a result, the spark gap distance between the electrode and work piece increases. Enlarged spark gap distance makes the flushing of debris uniform. This results in much stable process thereby improving material removal rate and surface finish.

Design layout and measurements:
A large number of input process parameters can be varied in the EDM process, each having its own impact on output parameters such as MRR, and surface roughness. Various input parameters are:

- Discharge voltage
- Peak current
- Frequency
- Pulse on time
- Pulse off time
- Polarity
- Electrode gap
- Type of dielectric flushing

The design variables can be summarized as follows:

- Copper powder is mixed in the dielectric medium.
- 5 levels in terms of 4 grams per liter concentration of powder is used for conducting experiments.
- Four levels of peak current.
- EDM oil and deionized water is used as dielectric medium.

Dielectric medium	Electrode Diameter	Voltage	Current	T_{on}	T_{off}	Powder	Flushing Conditions
EDM oil	Copper rod of 8mm	60V	2 to5 A	120 µsec	120 µsec	Copper-45microns 90% purity	2 liter per minute

Table 4.1: Selected parameters

S. No	Parameter	Units	Actual range	Selected range	In steps of
1.	Current	Ampere	0-5	2 to 5	1
2.	Concentration	g/L	-	0-12	3

Table 4.2: Machining parameters

The two most important output parameters MRR and surface roughness are selected as response parameters for this work. Surface roughness is significant from the point of view of lubrication retention and quality of the products made from these tools. The objective of the experimentation is to study the effect of powder mixed dielectric upon the MRR, and surface roughness using High carbon high chromium steel (H.C.H.Cr) as work material. Experiments were conducted as under

1.Experiments without adding powder in dielectric medium.
2.Experiments with Copper powder as additive.

Experimental procedure

1. Preparation of work piece samples and weighing them.
2. Weighing and packaging of copper powder in 2 gram packets.
3. Work piece is placed on fixture in dielectric fluid tank and flushing tube is positioned in between tool and work piece.
4. Power supplies are switched on and program is executed in the computer for controlling tool movement.
5. By giving rapid motion command in GUI from computer, machining is carried out.
6. Final weight of work piece is noted and continuing experiments by adding different concentration of powders.
7. MRR is calculated and surface roughness is measured.
8. Analyzing the MRR and surface roughness by addition of powder in dielectric medium.

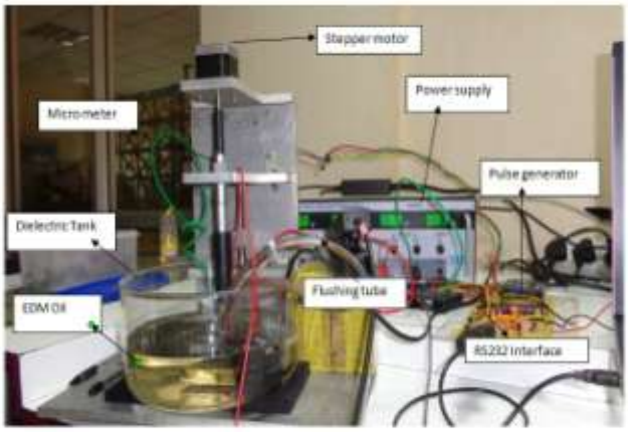


Figure 4.1 Experimental set up

Electrodes used :

Copper electrodes of diameter 8mm and 0.9 mm and are used for conducting experiments as shown in Fig 4.2 and Fig 4.3

Fig 4.2: Electrode diameter of 8mm

Table 4.3 Technical Specifications

Technical specifications of EDM setup	Travel length		Speed			Least step size	
	25mm		Max-0.0039m/sec , Min-3.8µm/sec			39 nm	
Work piece material	Carbon (%)	Chromium (%)	Manganese	Phosph-orous	Vanadium	Molyb-denum	Sulphur
	1.5	11-13	0.45	0.030	1.0	0.9	0.3
Powder composition	Material		Particle size		Mesh	Percentage purity	
	Copper		45µm		325	95%	

Fig 4.3: Electrode diameter of 0.9mm

Micro EDM:

According to the literature there is no much difference between micro and macro EDM, because only tool dimension and electrical parameters like current, voltage, pulse on and pulse off time are changed in micro machining. Micro machining is the one of the most powerful methods for fabricating micro holes and three dimensional features in conducting and semiconducting materials. Few micro holes are made on the 0.3mm Aluminum sheet by using 0.9 mm copper electrode and deviations are observed using Zeiss sterio microscope.

Table 4.4 Parameters taken for micro machining

Dielectric medium	Deionized water
Voltage (v)	60
Current (A)	0.5
$T_{on} = T_{off}$	120µs

V.RESULTS AND DISCUSSIONS

Experimental results of PMEDM:

Experimental results of EDM machining with and without the use of powder mixed in dielectric medium are discussed.

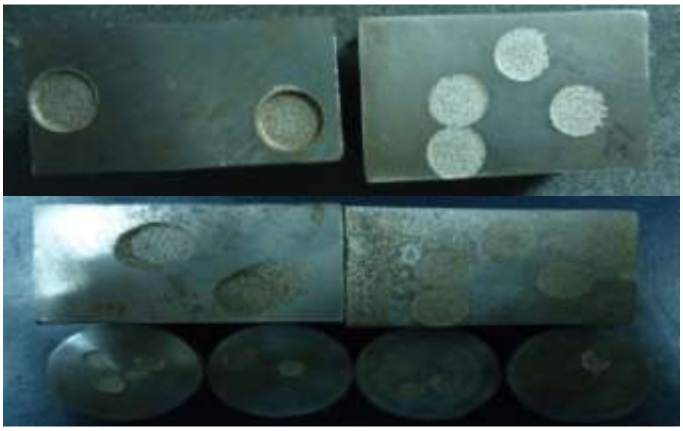


Fig 5.1 Photograph of machined work pieces

Voltage and current pulse trains during machining:

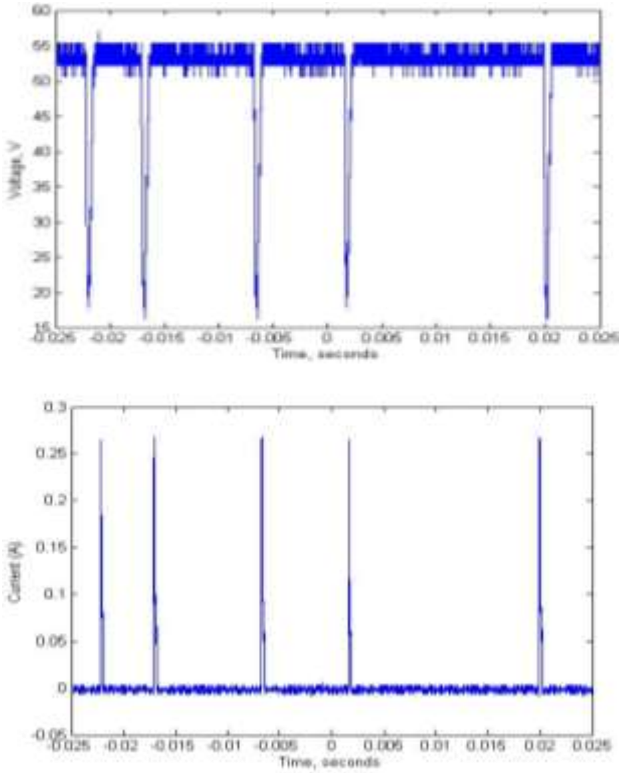


Fig 5.2 Voltage and Current pulse trains during machining at 2 grams of powder concentration

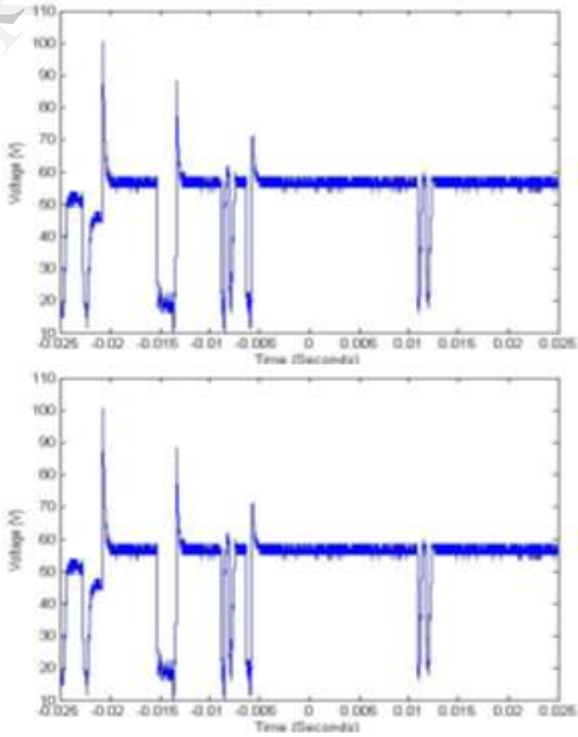
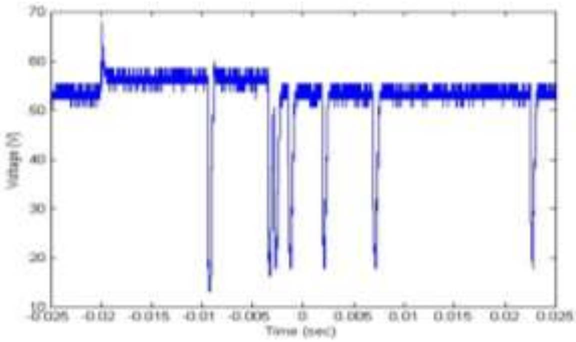


Fig 5.3 Voltage and Current pulse trains during machining at 4grams of powder concentration



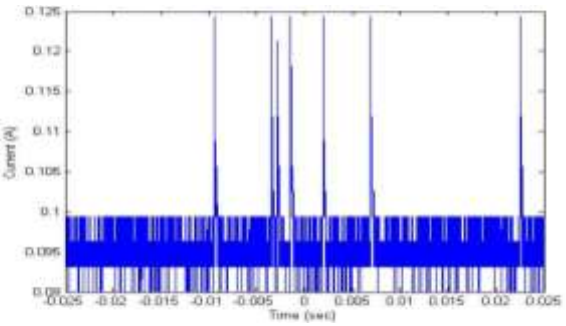
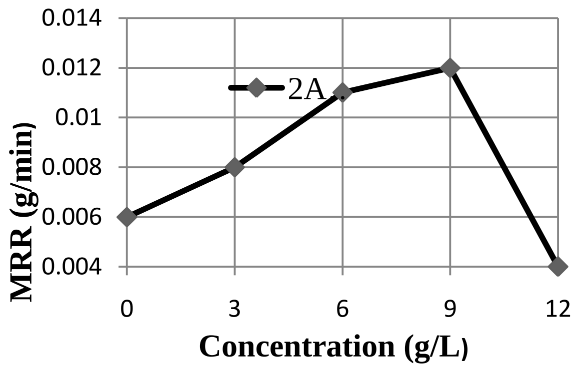


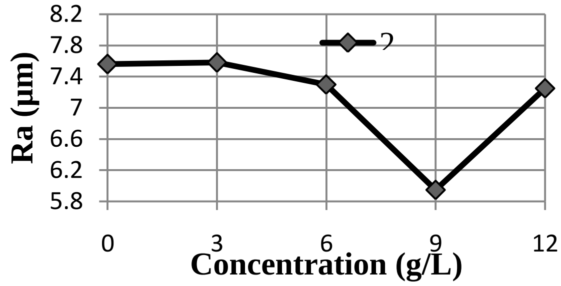
Fig 5.4 Voltage and Current pulse trains during machining at 6 grams of powder concentration

The voltage and current pulse trains shown in figures 5.1 to 5.4 explains that, as increase in the concentration of powder in dielectric medium sparking frequency increases which results in high MRR and decrease in surface finish. Frequency increases due to early explosions takes place by adding powder in medium which results in high MRR

Observations:



(a) Variation of Material Reomval Rate with change in powder concentration

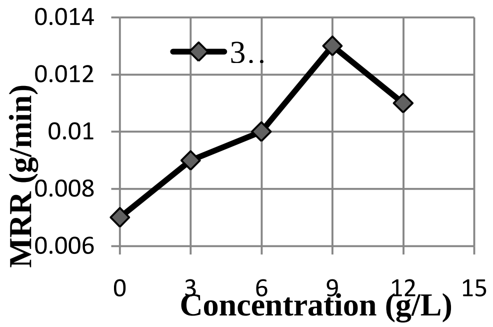


(b) Variation of Surface roughness with change in powder concentration

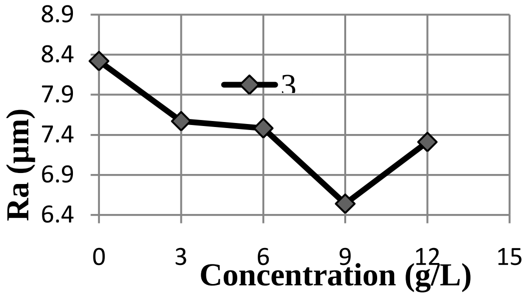
Table 5.1 Effect of powder on surface finish and MRR at 60V

S.No	Current (A)	Concentration (g/L)	Machining time (min)	MRR(g/min)	R_a(µm)
1	2	0	10	0.006	7.56
2	2	3	10	0.008	7.58
3	2	6	10	0.011	7.30
4	2	9	10	0.012	5.95
5	2	12	10	0.004	7.25
6	3	0	10	0.007	8.32
7	3	3	10	0.009	7.57
8	3	6	10	0.010	7.48
9	3	9	10	0.013	6.53
10	3	12	10	0.011	7.31
11	4	0	10	0.009	8.54
12	4	3	10	0.011	7.97
13	4	6	10	0.013	7.51
14	4	9	10	0.014	7.10
15	4	12	10	0.010	7.36
16	5	0	10	0.011	9.00
17	5	3	10	0.011	8.30
18	5	6	10	0.012	7.93
19	5	9	10	0.014	7.53
20	5	12	10	0.009	7.82

Fig.5.5 Variation of MRR and surface finish at 2Amperes

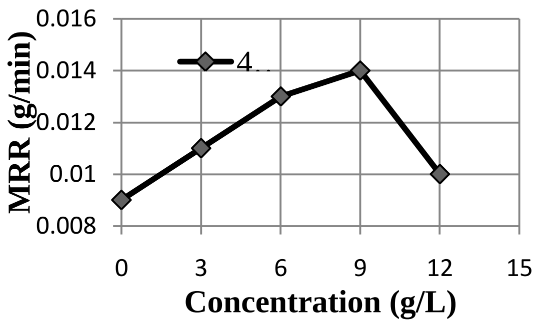


(a) Variation of Material Reomval Rate with change in powder concentration

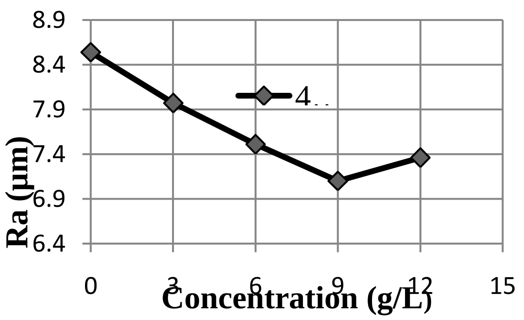


(b) Variation of Surface roughness with change in powder concentration at 3 Amperes

Fig.5.6 Variation of MRR and surface finish at 3 Amperes

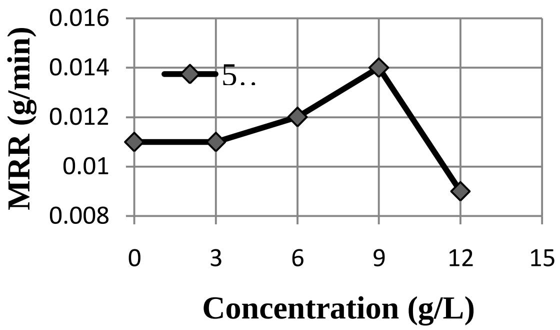


(a) Variation of Material Reomval Rate with powder concentration

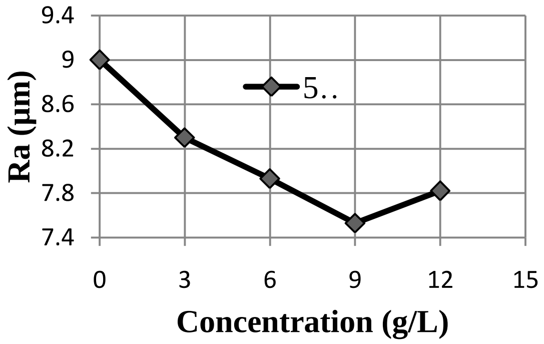


(b) Variation of Surface roughness with powder concentration at 4 Amperes

Fig 5.7 Variation of MRR and Surface finish at 4 Amperes



(a) Variation of Material Reomval Rate with powder concentration at 5 Amperes



(b) Variation of Surface roughness with powder concentration at 5 Amperes

Fig 5.8 Variation of MRR and Surface finish at 5 AmperesFrom Fig 5.5(a) to 5.8(a) it can be observed that the MRR without powder is low. With the addition of Copper powder, faster sparking takes place between tool and work piece causing faster erosion from the work piece surface. As concentration is increasing, the debris and powder gets accumulated between tool and the work piece which results in short circuiting of the process. Due to short circuiting, machining becomes unstable which results in low MRR.

Fig 5.5(b) to 5.8(b) explains that surface roughness decreases by adding copper powder in dielectric fluid. Added powder enlarges and widens the discharge gap between the tool and the work piece. This results in the easy removal of debris, which leads to improvement in surface quality. The powder particles distribute the spark energy uniformly. This results in shallow craters on the work piece surface. The results obtained from the experiments lead to the conclusion that the addition of copper powder improves the Surface finish and MRR.

*Analysis of micro holes:*All experiments are conducted at constant parameters as mentioned in Table 4.6

Fig 5.9 (a) Bottom side of micro hole using 0.9 mm copper tool

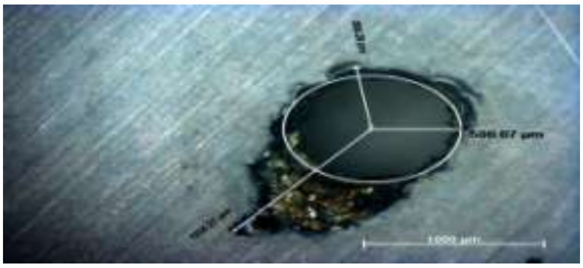


Fig 5.9 (b) Top side of micro hole using 0.9 mm copper tool

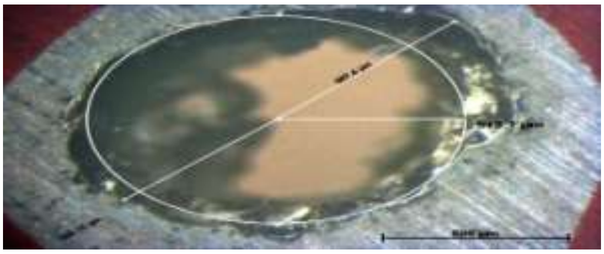


Fig 5.10 (a) Top side of micro hole using 0.9 mm copper tool

Fig 5.10 (b) Bottom side of micro hole using 0.9 mm copper tool

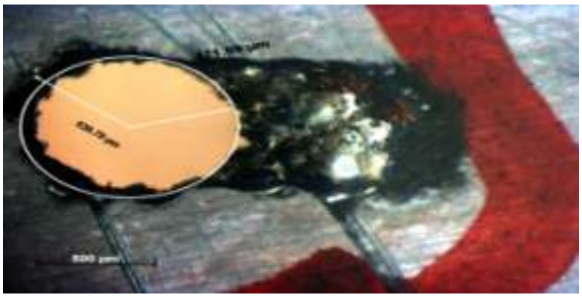


Fig 5.11 (a) Top side of micro hole using 0.9 mm copper tool

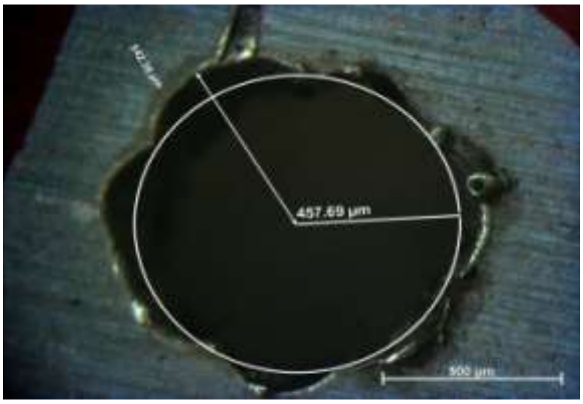


Fig 5.11 (b) Bottom side of micro hole using 0.9 mm copper tool

The work piece is getting welded to the tool when experiments were conducted at 60 volts and 2 amps current resulting in unstable machining due to short circuit. To avoid this, the current was changed to 0.5 amp and the experiments were carried out without any short circuit during machining. Figures 5.9 to 5.11 show the machined holes and deviations can be seen in respective figures.

VI. CONCLUSIONS

An EDM set up is developed using stepper motor, micro step driver and micrometer. A least step size of 39 nano-meters is achieved when micro step driver is set to 12800 steps per revolution. Tool movement is controlled using gap voltage as feedback, and few experiments are carried out in the EDM set up with and without using powders. The results of the present study show the variation of process performance indices such as MRR and surface roughness with respect to powder concentration. The conclusions drawn are as follows;

1. Copper powder mixed in dielectric fluid affected MRR and surface roughness.
2. By increasing the concentration of powder in dielectric medium results increase in MRR and decrease in Surface finish up to certain concentration
3. High concentration of powder 12(g/L) reduces the MRR and increases the surface roughness.

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