THERMAL ENERGY DISTRIBUTION AND OPTIMIZATION OF PROCESS PARAMETERS DURING ELECTRICAL DISCHARGE MACHINING OF AISI D2 STEEL

A THESIS SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

in

Mechanical Engineering

By

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National Institute of Technology
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Under the guidance of

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CERTIFICATE

This is to certify that thesis entitled, "**THERMAL ENERGY DISTRIBUTION AND OPTIMIZATION OF PROCESS PARAMETERS DURING ELECTRICAL DISCHARGE MACHINING OF AISI D2 STEEL"** submitted by Sangram keshari Mohanty (roll no-110ME0311) in partial fulfillment of the requirements for the award of bachelor of Technology Degree in Mechanical Engineering at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other university/ institute for award of any Degree or Diploma.

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Abstract

Electro discharge machining has gained significance because of wide range of advantages like cutting variety of material and its alloys with complicated shapes and high accuracy. The effectiveness of electro discharge machine can be calculated in terms of material removal ness, relative tool wear ratio, surface roughness, etc. The total electrical energy is transferred into various parts like work piece, tool, dielectric fluid and energy in eroded particle from both tool and work piece. By calculating energy transferred to each at different parameters we can optimize it in order to get the required parameter for the specific requirement. Since one of the most important aspects of EDM is to machine intricate shapes, in this case the prevention of tool erosion is very much important factor. By using simple conduction equations, we can calculate the energy transferred to each for material removal rate and tool wear rate. Also energy transferred to work piece, tool can be calculated by using conduction equation and the best suited input parameters can be found for the maximum energy transfer to work piece. In this research, a complex shaped tool was fabricated and machining operation was done at different input parameters in order to get the same impression of the tool on the work piece. After than energy responsible for tool wear were calculated and the optimum parameter are found in order to minimize the tool wear. The change in shape of tool, reduction of the area also observed after several experiments. Various graphs showing the variation of fraction of energy transferred to tool, work piece are plotted. Variation of material removal rate and tool wear rate, surface roughness with the input parameter are plotted in the graphs. Thus from the graphs, optimum parameters can be found in order to know which set of parameters suits for the desire output and can be applied in industry for the same purpose.

CONTENTS

CHAPTER 01 INTRODUCTION

BACKGROUND

With the development of technology and industrial growth there arises new materials which are harder, difficult to machine, high strength to weight ratio, heat resistant which have a wide application in the industrial field like aerospace, nuclear physics, missile, etc. New developments in the field of material science led to development of composite materials and high tech ceramics having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by spark erosion. The machining of such material finds difficulties in case of conventional machines. New concept of machining called non-conventional machines uses energy form like sound, light, electrical, chemical, electrons, and ions. The needs like more surface finish, high accuracy can be meet with no-traditional technologies. One of the non-conventional machine which uses electrical form of energy for machining is electro discharge machining.

Electrical Discharge machining (EDM) has been replacing drilling, milling, grinding and other traditional machining operations and is now is a vital machine for wide variety of application in industries. It is capable for machining of geometrically complex, hard material with high accuracy. Materials like heat treated tool steels, composites, super alloys, ceramics, hastalloys, nitralloy, nemonics, carbides, heat resistant steels etc can be easily machined with EDM. 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.

PRINCIPLE OF EDM:

EDM process is thermo-electric in nature and eradicates material from the work piece by sequences of discrete sparks between tool and work electrodes immersed in a dielectric medium. The electrode is moved towards the work piece until the gap is small enough to ionize the dielectric. A Short duration discharges are produced in a liquid dielectric gap, which separates tool and work piece. The dielectric fluid flushes the eroded particles from the gap and it is truly important to maintain the flushing continuously.

The material is removed with the erosive effect of the electrical discharges from tool and work piece. Since there is no direct contact between electrode and work piece there presents no mechanical stresses, chatter and vibration problems during machining. As the erosion is produced by electrical discharges, both electrode and work piece must be electrically conductive. Thus the machining force is much smaller than that in conventional process, because molten metal can be removed with a very small flushing pressure. EDM uses electric energy by discharge which occurs as a result of dielectric breakdown between positive tool electrode and negative work piece. When tool electrode approaches to a work piece, the electric field between tool and work piece is becomes larger and then spark occurs. This is known as the fluid-ionization point and it is based on the dielectric strength of the fluid and the distance between the electrode and work piece. When discharge occurs, the voltage drops about to the range of from 25V to 45V. Within the ionized column, electrons detached from the dielectric-fluid atoms and flow from the negative-polarity tool toward the positive-polarity work piece. As the dielectric-fluid atoms in the column are missing electrons, they are positively charged, and flow from the positive polarity work piece toward negative-polarity electrode. This streaming of electrons and positive ions is known as plasma channel. Plasma channels that are surrounded by bubbles which occur by vaporization of dielectric fluid grow during on-time.

Four successive steps by which an electrical discharge between the tool electrode and the work piece proceeds:

1. The ignition phase
2. Formation of the plasma channel
3. Melting and evaporation of a small amount of work piece material
4. Ejection of the liquid molten material

CHARACTERISTICS OF EDM

1. Advantages of EDM

One of the main advantages of EDM is a consequence of the thermal process. It is based on: eroding material by melting and evaporation, so the hardness of the work piece is no limitation for machining. Even the hardest steel grades can be machined with almost same machining speed as for softer steels.

a) Machining hard materials

The capability of machining hard materials is a major benefit as most tools and moulds are made of hard materials to increase their lifetime.

b) Absence of forces

As the EDM-process is based on a thermal principle, almost no mechanical forces are applied to the work piece. This allows to machine very thin and brittle structures. It should be noticed that some small mechanical, electrical and magnetic forces are produced by the EDM-process and that, as already mentioned, flushing and hydraulic forces may become large for some work piece geometry. The large cutting forces of the mechanical materials removal processes, however, remain absent.

c) Machining of complex shapes

Complex cavities can frequently be machined without any problems by die-sinking EDM, provided an electrode is available, having the opposite shape of the cavity. In most cases, the soft electrode (Cu, graphite or W-Cu) can be machined rather easily by conventional processes as milling and turning or by wire-cutting EDM. In this way, complex cavities can be eroded, even on simple die-sinking machines which can only erode in the downward direction. Due to the modern NC control systems on die sinking machines, even more complicated work pieces can be machined.

d) High degree of automation

The high degree of automation and the use of tool and work piece changers permit the machines to work unattended for overnight or during the weekends.

e) Accuracy of the process

EDM is a process where very accurate structures can be machined (typically 1 to 5μm). In the case of work pieces with a higher thickness, the accuracy and the fine surface quality remains the same over the whole thickness of the work piece, due to the fact that EDM is machining with the same process conditions over the total work piece height.

2. Disadvantages of EDM

a) Tool as well as work piece has to be electrically conductivity.

b) Predictability of the gap is not always possible as tool wear is a unaccountable factor in EDM

c) Optimization of the electrical parameters has be done before machining in order to know the best suited parameter for the required output. The user has to develop his own technology.

d) Low material removal rate

3. Applications of EDM:

(a) In the machining of very hard metals and alloys used in aerospace, automotive and nuclear industries.

(b) 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.

(c) Application potential of EDM can be further enhanced if its machining rates can be increased and resulting surface damage to the work piece is accurately estimated and reduced.

OBJECTIVE OF THE PRESENT WORK

Problem statement: the most important aspect of electro discharge machining is to machine complex shapes. I order to print a complex impression on the work pieces a complex shaped tool is required. While machining there are chances that due to tool may get eroded and the final shape that we desire may not be possible entirely. So prevention of tool erosion is a very important aspect in such machining. Our investigation is a step towards the same

In the present work attempt has been made to find the energy distribution in EDM, i.e., fraction of energy transferred to tool, work piece, dielectric, energy responsible for material removal and tool wear. The variations of the energy with respect to primary energy are plotted in the graphs. Thermocouples ere used to measure the temperature difference in tool, work piece and dielectric and conduction equations are used to find the energy transfer to each. Focus is done mostly in order to minimize the energy responsible for tool erosion. The optimum parameters are found for low tool wear rate and high material removal rate.

CHAPTER 02 LITERATURE SURVEY

The earlier work related to the present research area by other researchers have been explored and the progressive account of the work has been enumerated here.

Harminder Singh(2012) developed a model to calculate the fraction of energy transferred to work-piece utilizing heat transfer equation at different edm parameter. Series of experiments on EDM of tungsten carbide (P20 grade) were conducted by using die sinking electrical discharge machine using copper-tungsten as tool carbide. It was concluded that fraction of energy transferred to work-piece and tool electrode which varies from 6.1% to 26.82% with current and pulse duration taken during the experiment. In general fraction of energy increases with current and maximum value is attained with increase in pulse duration. The value from study can be used for further experiment in future. The study also found the optimal combination of input parameter using ANOVA for maximum energy transferred to work-piece.

Yang Shen et. Al(2013) determined energy distribution during electro discharge machining of Ti-6Al-4V (an aerospace material, difficult to machine) at different parameter including inter-electrode distance, pulse duration, polarity and elecr=trode shape. The result of the study infers that energy distribution characteristics are greatly affected by power density i.e., higher power density, more energy transferred to electrode. The energy distribution ratio decreases with increasing inter-elctrode distance and pulse duration because of the expansion of discharge plasma. Energy distribution is also affected by the shape of tool used. A tool with needle shaped head has more energy distribution among work-piece and tool than that of disk shape headed tool.

A Okada et. Al.(2000) determined the energy distribution using graphite tool electrode by measuring temperature at different point in workpiece, tool and dielectric and later on putting these values in conduction, convection equations. The convection energy is very very less compared to that of conduction, so is neglected. It was concluded that MRR depends upon energy density and tool wear depends upon adhesion of heat resolved carbon from machining fluid. With increase in discharge current energy transferred to work-piece increases. Kerosene performs better than de-ionised water as a dielectric in terms of enrgy transferred to electrodes. Energy transferred to various part at different parameter are represented graphically.

M. Gostimirovic et.al. (2011) carried out experiment to find influence of discharge energy over material removal rate, gap distance, surface roughness and recast layer. The experiments were conducted using copper electrode while varying discharge current and pulse duration. Increase in discharge energy increases the MRR. For an optimal discharge duration energy (pulse duration), the MRR increases with increase in discharge current. Gap distance exert greater influence on machining accuracy of EDM. Surface roughness increases uniformly with increase in discharge energy. Also increase in discharge energy increases the recast layer thickness, while the discharge duration has more pronounced influence on the recast layer. Analysis of experimental parameter were conducted which allows selection of optimal input parameter for the selection of most favorable EDM conditions.

Shankar Singh et al. (2004) carried out experiment in order to study the effect of input parameter like pulsed current on material removal rate, diametric overcut, electrode wear and surface roughness in electrical discharge machining of En-31 tool steel (IS designation: T105 Cr 1 Mn 60) hardened and tempered to 55 HRc. The work material was machined with copper, copper tungsten, brass and aluminum electrodes by varying the pulsed current at reverse polarity. Surveys indicate that the output parameters of EDM increase with the increase in pulsed current and the best material removal rates are achieved with copper and aluminium electrodes. For Copper and copper–tungsten electrodes, the electrode wear rate is comparatively low for the tested work material. Aluminium electrode also shows good results while brass wears the most. It was inferred that copper is a better electrode as provides more surface finish, less diametrical overcut, high material removal and less tool wear for En-31 work piece material. Aluminium stand next to copper.

H.T. Lee et al. (2003) studied the relationship between input parameters in EDM and surface cracks by using a full factorial design, based upon different discharge current values and pulse-on time on D2 and H13 tool steels as materials. The development of surface cracks is explored by considering surface roughness, white layer thickness and the stress induced during the EDM process. Its use will provide a valuable assistance in improving the quality of the EDM process. Increase in pulse-on duration will increase both the average white layer thickness and the induced stress which tend to promote crack formation. When the pulse current is increased, the increase in material removal rate results in a high deviation of thickness of the white layer. Compared to a thin white layer, a thick white layer has a propensity to crack more eagerly.

C.H. Che Haron et al. (2001) established a relation between the EDM parameter current and the output factors like material removal rate and electrode wear rate. The material removal rate of the work piece material and the wear rate of electrode material were found by calculating the percentage of mass loss per machining time. It was concluded that the material removal rate and tool wear rate were dependent on the diameter of the tool and had a close relation with the input current. Low current was found appropriate for small diameter electrode while high current for large diameter of electrode.

<u>Modelling of EDM equation:</u>

The primary mode of heat transfer in EDM is believed to be conduction. There are many simplified models of heat conduction in EDM is available but basis of their equation is fourier heat conduction equation-

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial Z^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \qquad (1)$$

Where T is the temperature (K), r is the radial axis (m), z is the vertical axis (m), t is time (s), and a is thermal diffusivity of the material (m2/s) which can be written as:

$$a = K_t/p.C_p \qquad (2)$$

Where K_t is thermal conductivity of material, p is density, C_p is specific heat capacity. The important parameters which contribute to the accurate prediction by EDM models include the amount of heat input, radius of plasma spark and the thermo-physical properties of the material. The theoretical model of heat source assumes different types of heat source such as planar heat source, circular heat source and point heat source.

1. Plane heat source: according to Zingerman, if a heat source have infinitely large radius then it is considered as plane heat source and the equation for temperature profile is:

$$T(t) = \frac{(c\gamma)^{1/2}}{8(\pi k)^{3/2}} \int_s \mathrm{d}S \int_0^t Qt(t-\tau)^{-3/2} \exp\left[-\frac{r^2}{4a^2(t-\tau)}\right] \mathrm{d}\tau \qquad (3)$$

2. Circular heat source: If the radius of the heat source assumed to have a finite value then heat source is considered as circular heat source. Zingerman and Zolotykh used this model and find a very close relation between experimental and theoretical results. Zingerman gives the solution for circular heat source as:

$$T(t) = \frac{(c\gamma)^{1/2}}{8(\pi k)^{3/2}} \int_0^b x\mathrm{d}x \int_0^t Qt(t-\tau)^{-3/2} exp\left[-\frac{h^2+x^2}{4a^2(t-\tau)}\right] \mathrm{d}\tau \qquad (4)$$

3. Point heat source: The source radius and plasma channel diameter assumed to be very small for small discharge durations and for these problems heat source is assumed as instantaneous point heat source Zingerman gives the solution for point heat source as:

$$T(r,t) = \frac{c\gamma}{8(\pi k)^{3/2}} \int_0^t Qt(t-\tau)^{-3/2} \exp\left[-\frac{r^2}{4a^2(t-\tau)}\right] d\tau \qquad (5)$$

Using Gaussian distribution, the heat flux q(W/mm2) at radial distance 'r' from the axis of the spark (lm), as used by Joshi et al. and Ali for EDM model, is given by:

$$q(r)| = q_o \exp\left\{-4.5\left(\frac{r}{R_{pc}}\right)^2\right\} \qquad (6)$$

Where q_o is maximum heat flux and ca be calculated as:

$$q_0 = \frac{4.57 F_c VI}{\pi R_{pc}^2} \qquad (7)$$

Where F_c is fraction of total EDM spark power going to the electrode (W); V is discharge voltage (V); I is discharge current (Amp) and R_{pc} is plasma channel radius at the work surface (micro-meter).

Again for heat flux we can consider disk as well as point heat source. The flux for both source are:

$$q = \begin{cases} \frac{F_c VI}{\pi r_c^2}; & \text{disk heat source} \qquad (8) \\ \frac{F_c VI}{2\pi r^2}; & \text{point heat source} \qquad (9) \end{cases}$$

In the above value for heat flux equation the value for R_{pc} as used by joshi et.al. is

$R_{pc} = (2.04e-3)\ I^{0.43}\ t_{on}^{0.44}$

Thus the heat flux equation can be derived as follows which is used by joshi et.al.

$$q(t) = \frac{3.4878 \times 10^5 FcVI^{0.14}}{t_{on}^{0.88}} \exp\left\{ -4.5 \left(\frac{t}{t_{on}} \right)^{0.88} \right\} \quad (10)$$

Joshi et.al(2010) developed thermal-physical model for die-sinking EDM using finite element analysis. The analysis is based on assumption like Gaussian heat flux equation and spark radiation equation based on discharge current, on-time, latent heat of melting, etc., to predict the shape of crater cavity and to measure the MRR and influence of input parameter on it. The experimental as well as the predicted data were plotted and found to be in good agreement with each other. It was found that MRR increases with discharge current but generally decreases with discharge duration or t-on time.

CHAPTER 03 EXPERIMENTAL SET-UP

The set-up is for placing the thermocouple in proper place in accordance with the tool, work-piece and dielectric which is to be hanged on ceiling over the electro discharge machining housing. There has to be a proper gap in between the thermocouple attached to each of tool, work-piece and dielectric. In each experiment, measurement of the temperature has to be done simultaneously. So a controller and digitizer is used to display the data.

Preparing the set-up:

The set-up for the experiment is an extensive work and all the machine or machine tools used for the same are mentioned below

1. Power saw
2. Abrasive saw
3. Grinder
4. Center Lathe machine
5. Manual hand saw
6. File of different configuration
7. Hydraulic drilling machine (for drilling 24 mm hole)
8. Hand drilling machine (for drilling 3mm hole)
9. Electro discharge machine
10. Controller
11. Digitizer
12. Thermocouple
13. Digital Weighing machine
14. Tally-surf
15. Vernier caliper at different stages of measurement
16. Polishing machine attached with emery paper

The above said machines were used at different stages while preparing the set-up. The use of each of the machine at different stages of operation are mentioned below

1. Power saw: It was used to cut a work-piece from a raw metal job of diameter 100 mm and thickness 20mm.

2. Abrasion saw: the work-piece thus obtained, is further cut into small work pieces. On each work-piece, a single experiment was carried out in electro discharge machine.

3. Grinder: it was used in order to grind the sharp edges of the small work-pieces thus formed.
4. Center lathe machine: it was used for turning operation while preparing the tool for EDM out of copper raw material.

5. Manual hand saw: it was used in order to create different shapes on the tool.

   The tool that was prepared is not a simple round or rectangular structure. It has been made a geometrically complex shape, whose importance can be understood later on. The shape of the tool along with its cross section are shown in the figure below

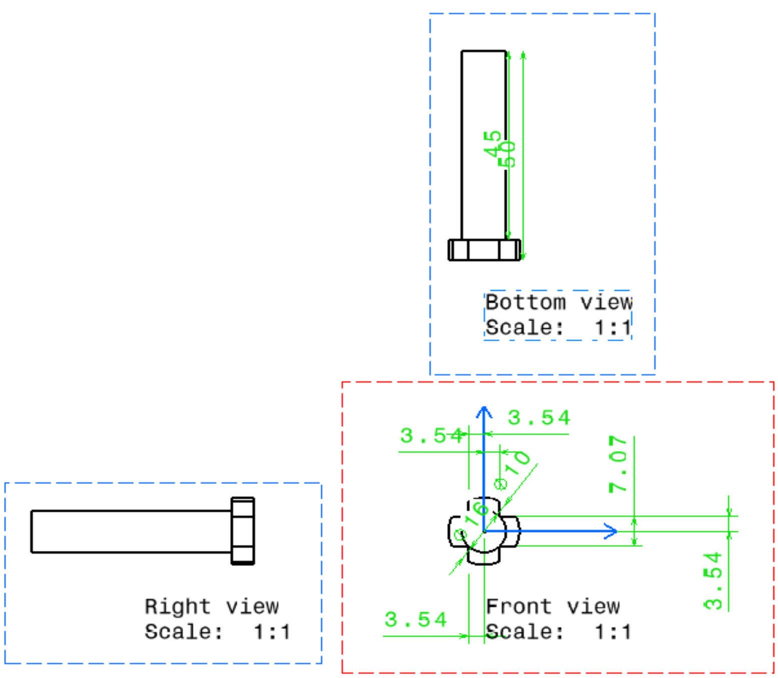

Fig.1. Design of the tool

6. File: it was used to polish the sharp corner of the face of the tool. After the plus shaped geometry was formed (as shown in figure), filing operation was done in order to make the surface smooth. Files with square cross section were used so that the impression we would get will have sharp edges perpendicular to each other.

7. Drilling machine: it was used in order to create holes in the tool and work pieces so that thermocouple can be placed intact. A picture showing the drills in tool is given below. Drill of 3mm diameter was done on work-piece as well as tool. The diameter of the thermocouple is slightly less than 3mm, so was fitted into the holes perfectly.

Fig.2. Tool used in EDM process along with the drills are shown.

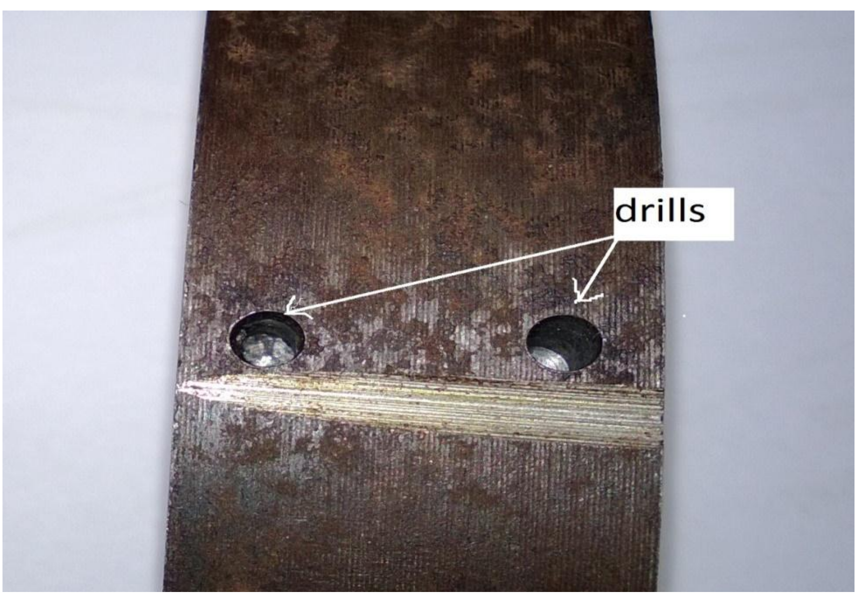

Fig.3. Drills in the work piece.

8. Electro discharge machine: It is the machine where all the experiments were carried out. Here the arrangements were made to fix the thermocouples to the work-piece, tool and di electric. The thermocouples were made to hang from a rigid support or a ceiling as shown in figure. Controller and digitizer were placed over it which was connected to different thermocouples as shown in figure.

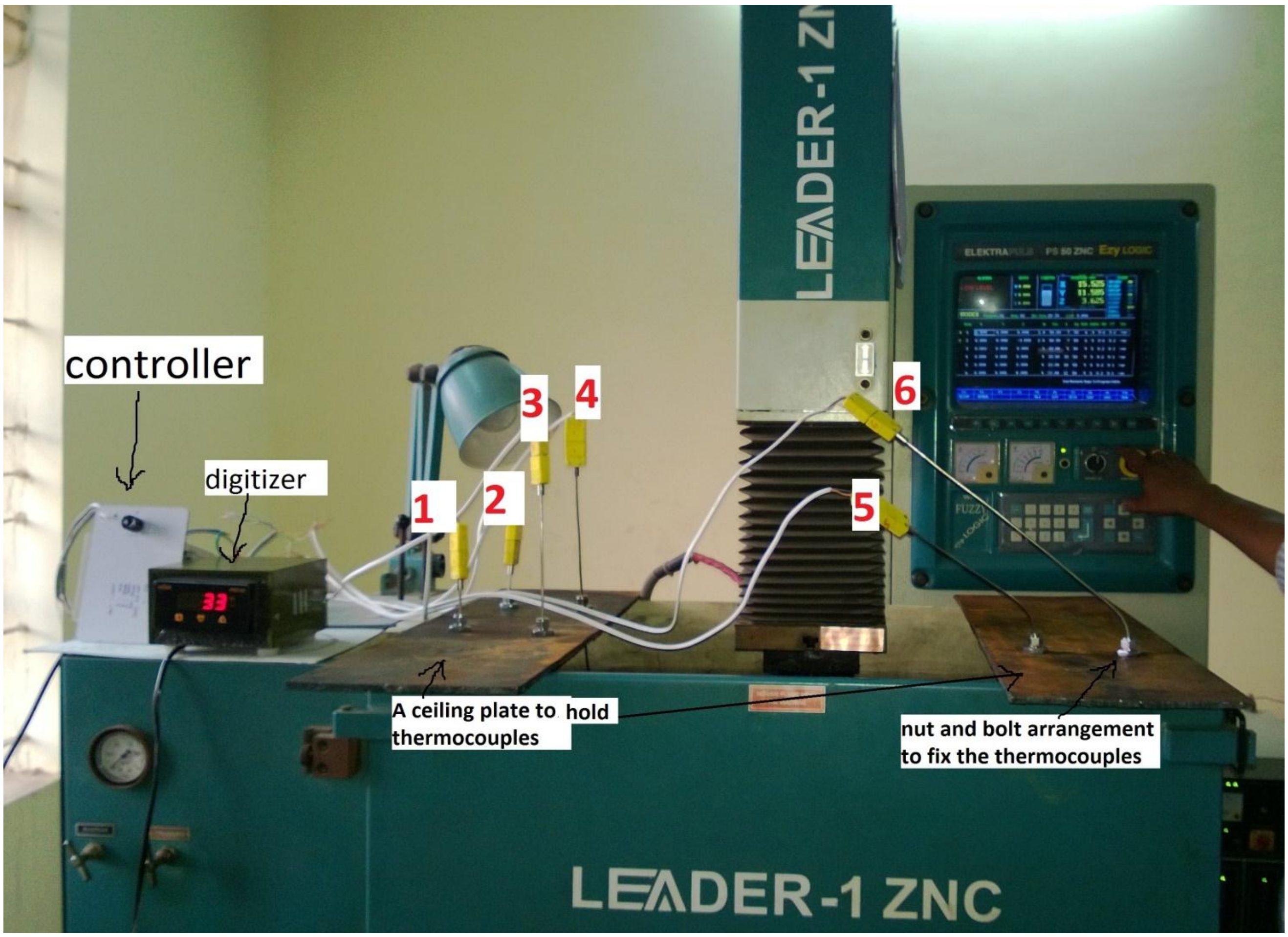

Fig.4. The whole set-up showing the EDM machine, thermocouples, controller, digitizer

9. Controller: as shown in the figure above, controller is the unit which controls the digitizer in order to show the temperature value of which thermocouple. It has a knob, which has the capacity to be fixed in six directions corresponding to six thermocouples.

10. Digitizer: it's the part of the set-up which responses to the data send by the thermocouple and provides the data in the form of digits. It was calibrated in order to show the temperature data in degree Celsius.

11. Digital weight measurement machine: to measure the weight of the work-piece and tool after each experiment in order to calculate the material removal rate and tool wear rate.

Fig.5. The digital weighing machine

12. Tally-surf: it was used to measure the surface rough ness of the machined surface. It was first calibrated with a given sample and then used over the EDMed surfaces to find the surface roughness after each experiment.

13. Hydraulic drilling machine: as shown in the figure, the nut and bolt arrangement for fixing the thermocouple, a drill has to be carried out on the ceiling plate of diameter 24mm. The thickness of the plate is 6mm, that's the reason for which it requires more power, so operation were carried out in hydraulic drilling machine. Total six drills were made in two plates in order to fix six thermocouples.

14. Vernier caliper: it was used at different stages of operation in order to check the measurement like diameter or length is perfect or not.

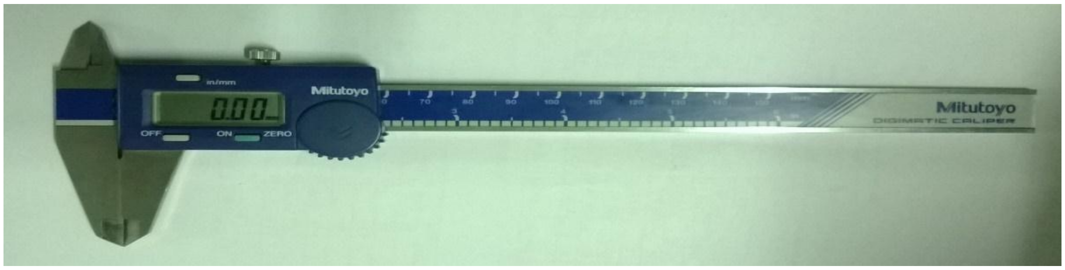

Fig.6. A digital Vernier caliper.

Thermocouple:

The thermocouples used in the experiment were **k-type thermocouple**. A k-type thermocouple has two legs, the positive leg is *chromel* and the negative leg is *alumel.* Chromel is an alloy with the following composition: 90% nickel,10% chromium whereas alumel has the composition as: 95% nickel, 2% manganese, 2% aluminium and 1% silicon. This is the most commonly used thermocouple with temperature range of -200°C to +1260°C / -328°F to +2300°F . The most important behavior of this thermocouple is that its sensitivity, it has sensitivity of approximately 41µV/°C, chromel positive relative to alumel. One of the constituent metals is nickel which is magnetic; a characteristic of thermocouples ended with magnetic material is that they experience a deviation in output when the material reaches its Curie point. The *curie point* for this thermocouple occurs at around 350 °C. A k-type thermocouple has sheath of metals like stainless steel or Inconel. Based on the environment where thermocouple is used like food storage, chemical beverage, metal bodies we choose the sheath accordingly to suit the environmental parameter.

How temperature is measured in k-type thermocouple: A thermocouple circuit comprises the two alloy junctions, wire sand connectors and a voltage measuring device. When the two junctions experiences different temperatures, a certain current flows through the circuit. The current is calculated based on temperature difference. As the measurement is relative, one of the temperatures essential to know in order to calculate an absolute temperature. This method is called calibration. First the reading in the voltmeter is set to a previously known temperature and other readings are taken relative to it.

These thermocouples have very first reaction time thus called quick response thermocouple (QRT). Depending upon how and where they are manufactured, they can be used in a temperature range of -200°C to +1260°C with errors within 0.5 to 2°C.

These thermocouples also have some disadvantages like the others. They must be calibrated very carefully before usage. Their output signals are very less, so they may have a problem with noise. These are prone to stress, strain and corrosion; particularly as they age. But it has a wide range of application.

The position of the thermocouples used in our experiment are shown in the figure below.

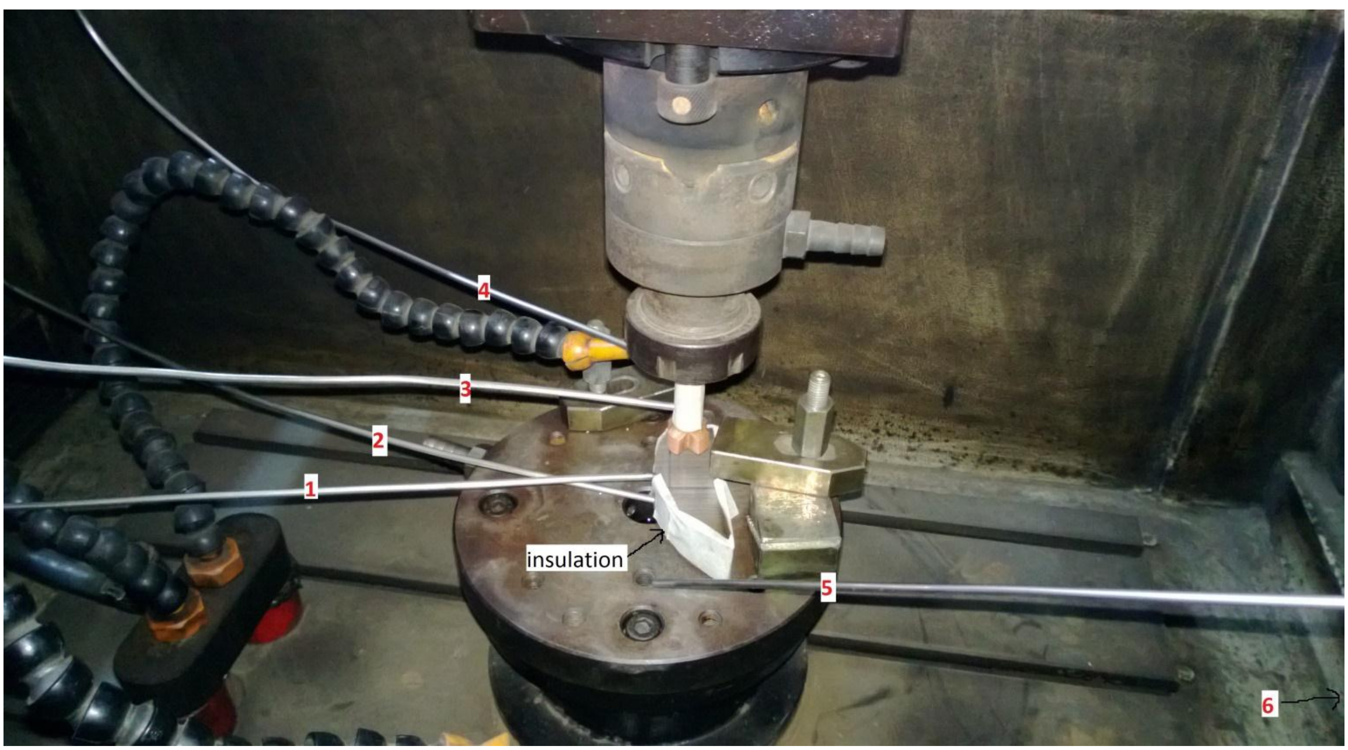

Fig.7. placement of thermocouples on the tool, work pieces (shown with numbering)

Fig.8. placing of thermocouple 5 and 6 in dielectric.

Total there were six thermocouple used. The position of each are shown in the figure. Thermocouple 1 and 2 were fitted to drills in the work-piece with a gap of 12mm; 3 and 4 were fitted to tool with a gap of 21mm. Thermocouple 5 and 6 were placed in the di-electric as shown in the figure at a radial distance of 5mm and 40mm from the spark point.

CHAPTER 04 MODELLING OF ENERGY DISTRIBUTION

Several researches have been done on energy distribution by using simple conduction equation as the primary mode of energy transfer and electrical energy will be transformed into heat on the material surfaces. Models used by konig, Singh H, Okada A et.al, Zhang Y et.al have developed model based on the following concepts.

The total input energy per unit time is

$W = VIt_i f$

Where $f = 1/(t_i+t_o)$

t_i = on time

t_o = off time

The total energy W will spilt basically into three different modes, i.e; energy into work piece, tool, dielectric. The rest energy will show up in the form of light energy, sound energy, radiation energy, etc.

The energy transferred to electrodes (tool and work pieces) will be categorized as stored energy, conduction energy and energy responsible for material removal. There is also convection mode of energy transfer but can be neglected as it is negligible compared to conduction energy as assumed by Okada A et.al. the stored energy is a time dependent energy, i.e; after a certain time how much energy is stored in the electrode. It will become constant after a certain time, or in steady state stored energy becomes negligible as assumed by Singh H. the conduction energy is the primary mode of energy transfer whose value is profound in the total energy transfer. It is assumed that heat is conducted into work-piece as well as tool in axial direction because in radial direction a thick tape of Teflon insulation is provided. The energy required for material removal is the energy which is responsible to melt and vaporize the electrode material. The temperature reached at the plasma is more than 10,000kelvin which is responsible to even vaporize the material. This energy dependable on material removal rate (MRR) and tool wear rate (TWR).

The stored energy at a moment t_x can relative to any time can be calculated as follows

$Q = [Q(t_x) – Q(t_{x-1})]/ (t_x - t_{x-1})$

It can be considered as negligible after a certain moment of time.

The energy responsible for conduction in work piece and tool can be calculated as

$Q = kA(T_1-T_2)/ (x1-x2)$

Where A = cross sectional area of the electrode

Energy conducted to di-electric will be given by

Q = 2.(Pi).k h(Td1 – Td2)/ln(r1/r2)

Where h = height of the dielectric exposed to the tool and work-piece.

And Pi=3.14

Energy responsible for material removal and tool wear, i.e; energy required to melt and evaporate the eroded particle is given by

E = v.p[c(Tv - To) + Lm + Lv]

Where Lm = latent heat of melting

And Lv = latent heat of vaporization which can be considered zero if there is no vaporization.

Some assumptions made while calculating the energy distribution EDM

- The energy transferred in radial direction is negligible as compared to energy transferred in axial direction in both work-piece and tool.
- The convection heat transfer is less comparable to conduction heat transfer.
- The efficiency with which the primary energy is transferred to all other medium is taken as 100%.

CHAPTER 05 OBSERVATION AND DISCUSSION

Electro discharge machining of D2 steel named as work piece were carried out in die sinking electric discharge machining with copper as tool electrode and by varying the different in put parameters. Thermocouple were placed at each position as shown in figure in order to note down the temperature at different points in due time. Values of all the temperature reading at each different input parameter are given in the table. The voltage supplied is 50Volt and initial temperature was 36 degree Celsius.

Table 1. Temperature values at various point in work piece, tool and dielectric

Current I_p(A)	Pulse duaration Ton (us)	T1(degree Celsius)	T2(degree Celsius)	T3(degree Celsius)	T4(degree Celsius)	Td1(degree Celsius)	Td2(degree Celsius)
2	50	45	42	45	43	41	39
2	100	47	40	46	44	40	39
2	200	47	39	47	44	39	37
10	50	53	40	52	41	38	37
10	100	60	41	57	43	38	36
10	200	58	43	56	44	40	38
18	50	60	41	67	43	40	39
18	100	60	43	62	41	42	39
18	200	64	42	66	44	41	39

Table 2. Tabulation for energy transferred to work piece, tool and dielectric and their fractions.

Current I_p(A)	Ton (us)	E(total) (watt)	E(w/p)	E(tool)	%E(w/p)	%E(tool)	E(dielectric)
2	50	70	5.625	14.5	8	20	0.0575
2	100	80	15.04	14.44	18	18	0.0575
2	200	90	17.18	21.76	18.8	21.76	0.0575
10	50	400	49.325	79.805	12	19	0.0287
10	100	450	72.09	101.33	16	22	0.0575
10	200	350	56.91	86.85	16.26	24	0.0575
18	50	810	119.7	173.7	14.77	21.44	0.0575
18	100	630	113.4	151.98	18	24.12	0.0862
18	200	720	138.6	173.7	19	24.12	0.0862

The fraction of energy transferred to work piece, tool was calculated by dividing the energy transferred to each by the total energy produced during an experiment. The variation among the fraction of energy transferred with respect to input parameters are depicted in the graphs shown below. Different graphs showing the variation of energy transferred Vs current or pulse duration is depicted in the graphs. Also the behaviors of the graphs are studied in details.

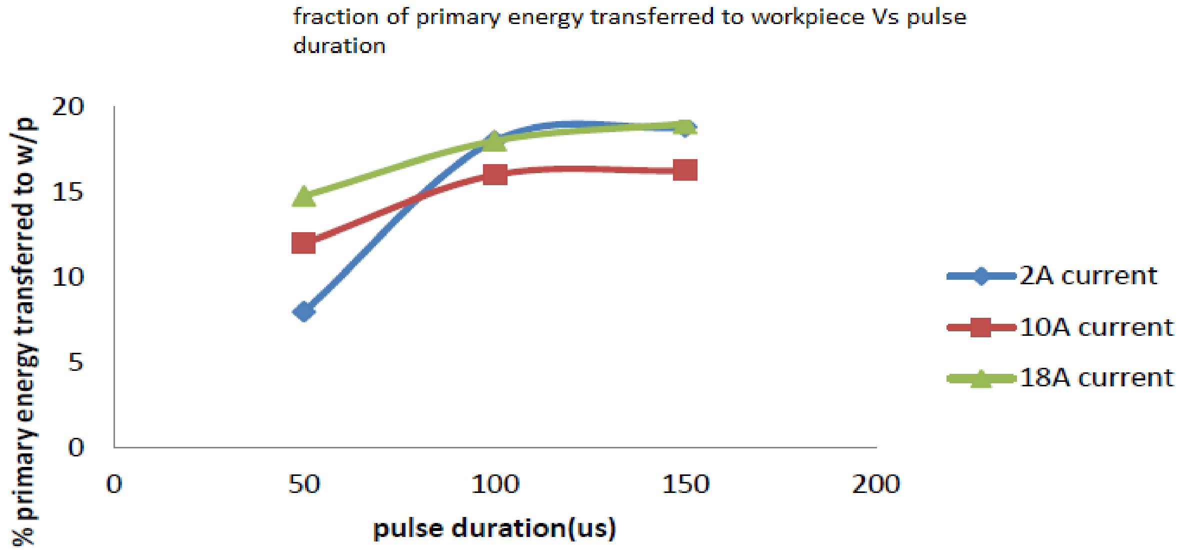

Fig.9. Effect of pulse duration on percentage fraction of energy transferred to work piece.

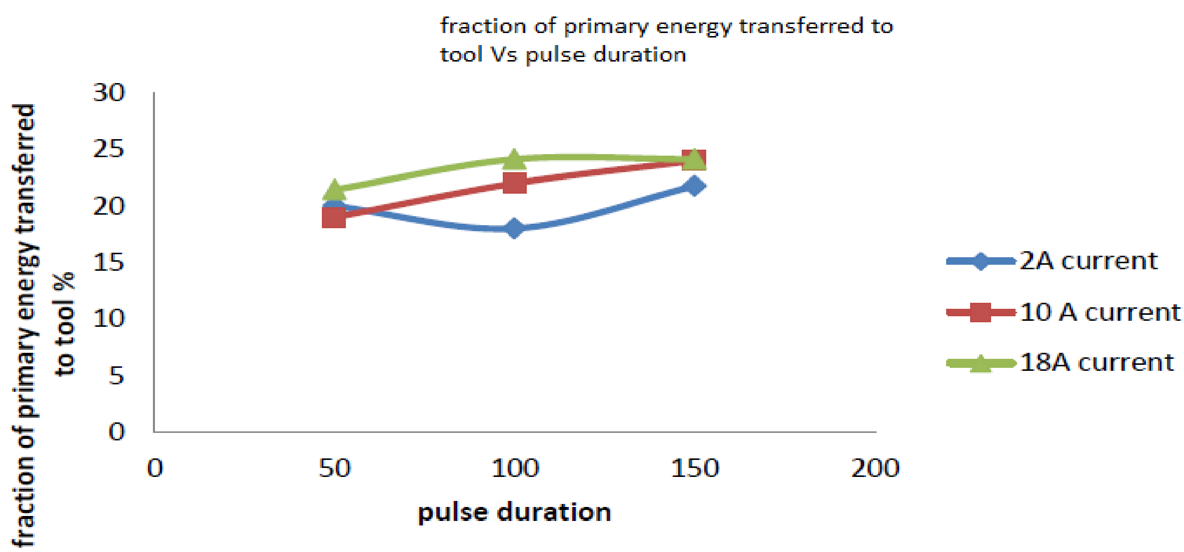

Fig.10. Effect of pulse duration on percentage fraction of energy transferred to tool

From the graphs it is obvious that with increase in pulse duration, the fraction of energy transferred to work piece or tool increases but except the curve for 2A current in fig. (b). the anomaly of the curve can be explained as follows. With 2A current the the energy transferred to electrodes are very less. When the pulse duration increases from 50us to 100 us, i.e; discharge remains for longer duration, so plasma channel radius or area increases. Thus energy density is less. So the relative fractions of energy transferred to electrodes are less. But in other graphs with increase in pulse duration the energy transfer increases as it overcomes the phenomenon of low energy density situation.

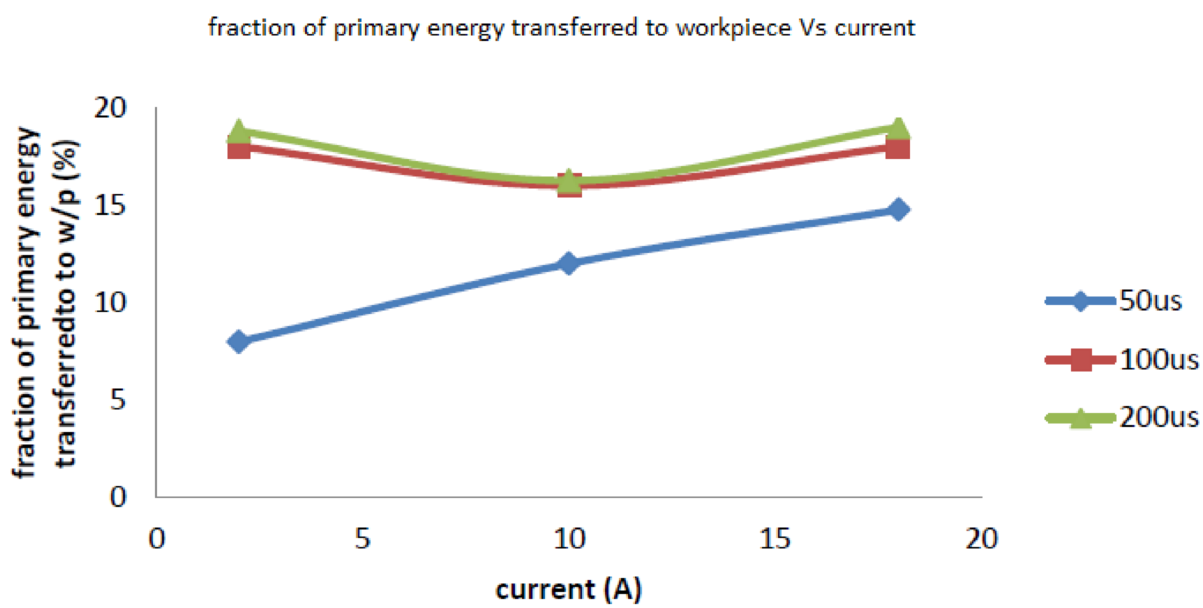

Fig. 11. Effect of current on percentage fraction of energy transferred to work piece.

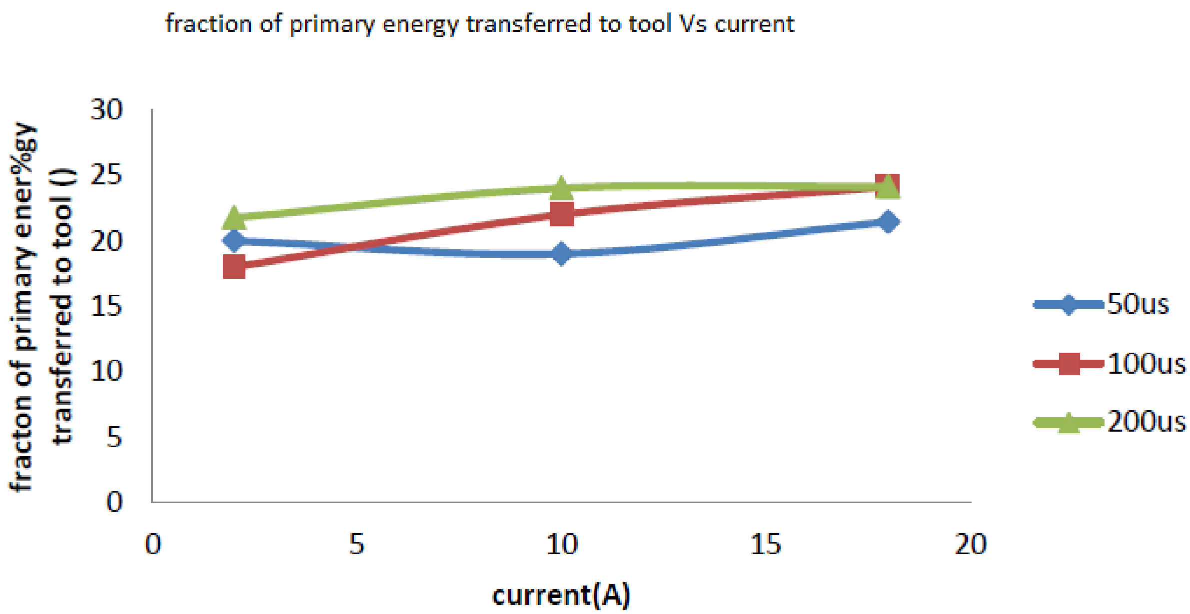

Fig.12. Effect of current on percentage fraction of energy transferred to tool

From the above two graphs [fig c, fig d] it is observable that with increase in current the fraction of energy transferred to electrodes increases. But the anomaly behavior of the graphs in fig (c) for 100us and 200 us can explained as same for the reason of anomaly of the graph for 2A in fig (b). in high pulse duration situation with increase in plasma area, the energy density decreases. Thus energy transferred also decreases.

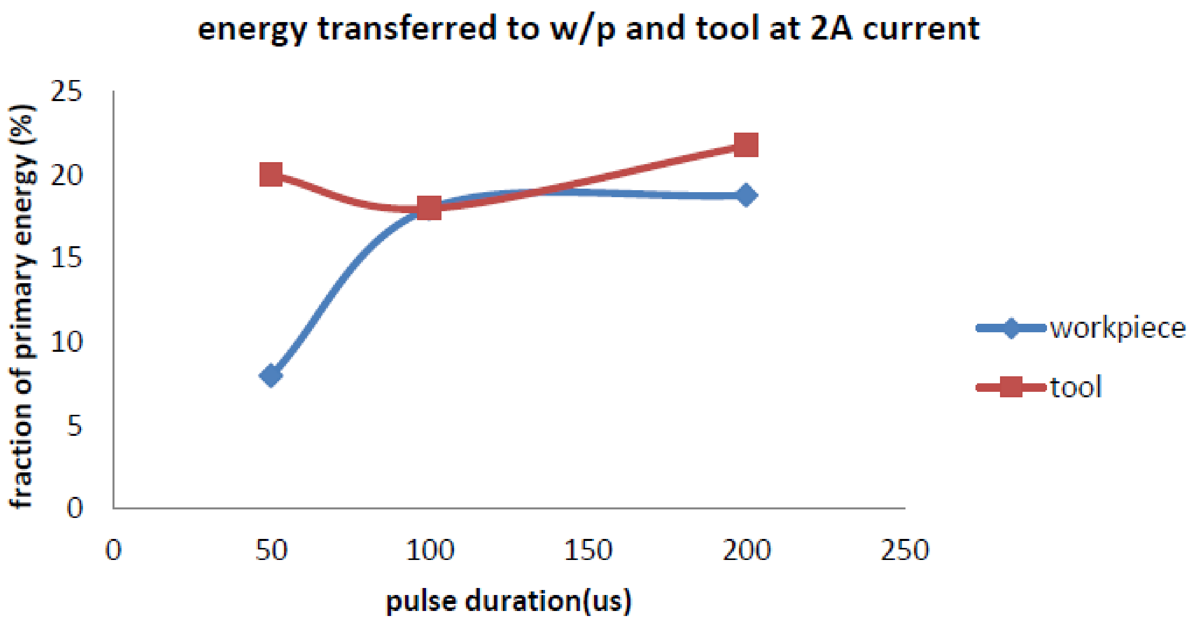

Fig. 13. Comparison between pulse duration and percentage fraction of energy transferred to tool, work pieces at 2A current.

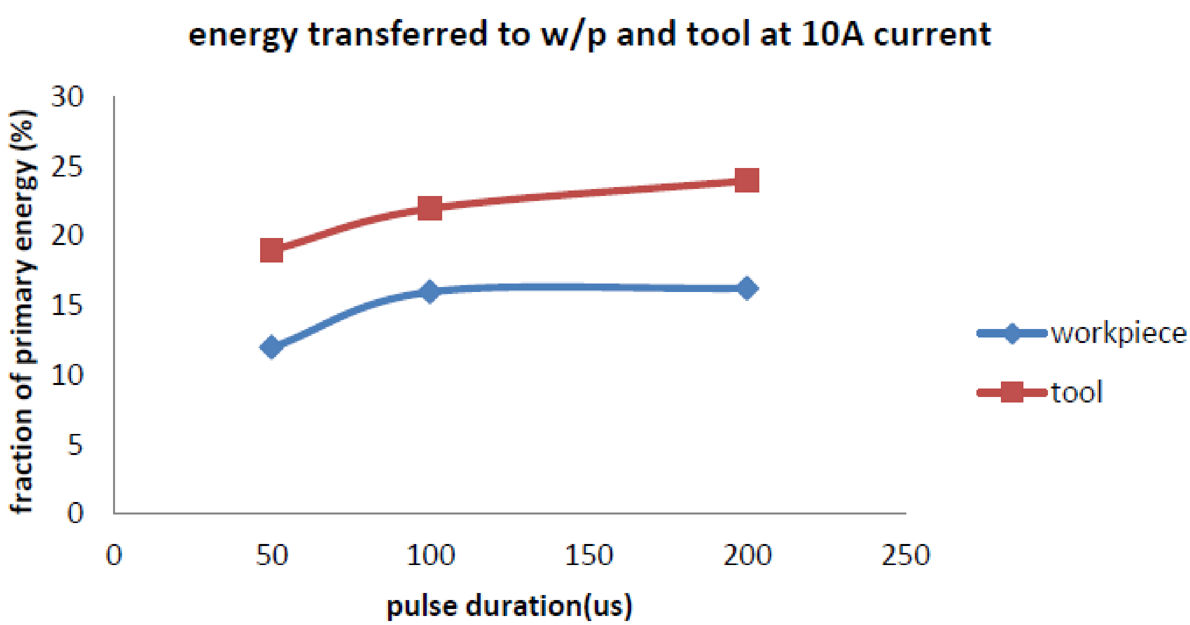

Fig.14. Comparison between pulse duration and percentage fraction of energy transferred to tool, work pieces at 10A current.

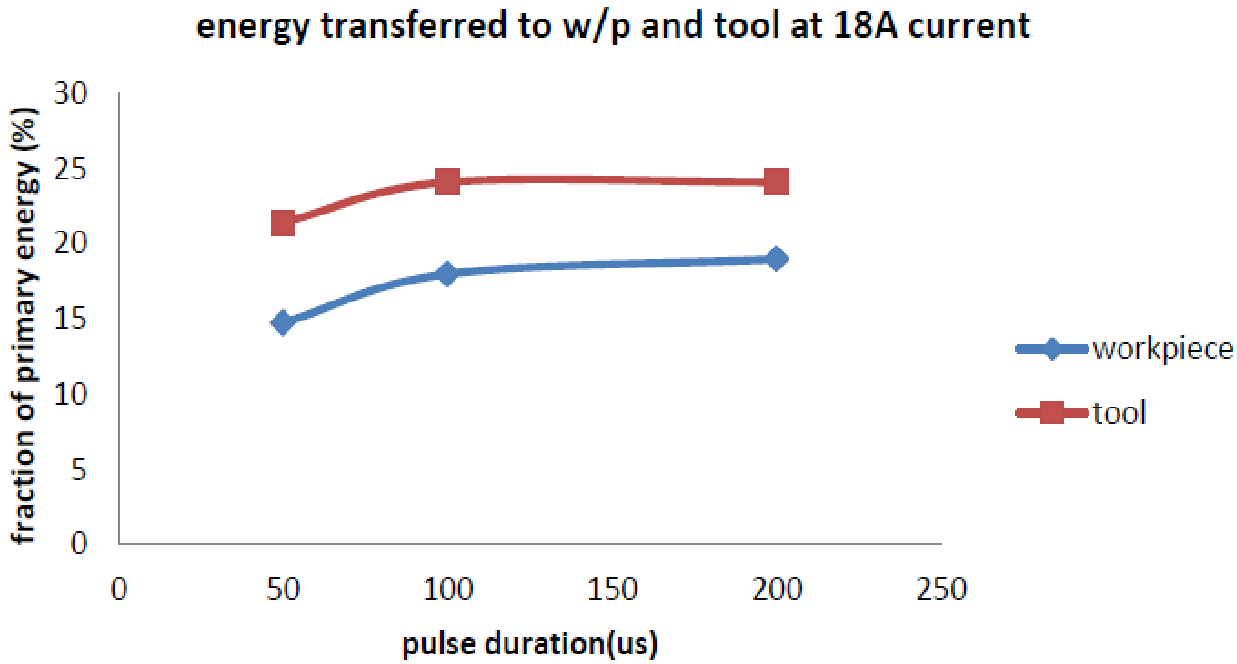

Fig.15. Comparison between pulse duration and percentage fraction of energy transferred to tool, work pieces at 18A current.

So from the above graphs it is a general conclusion that fraction of energy transferred to tool or work piece increases with pulse duration and current. In few cases only with increase in pulse duration the fraction decreases. It totally depend upon the properties of material like conductivity, heat capacity, melting and evaporation temperature, etc. the phenomenon for material removal also affects the energy transferred to electrodes. With increase in discharge time, more energy is transferred to material removed by melting or evaporation. This also terribly decreases the energy transferred to electrodes.

Table. 3. Variation of material removal rate and tool wear rate with respect to different input parameter.

Ip (A)	Ton	MR (mm3)	TW (grams)	MRR (grams/min)	TWR (grams/min)	MRR (mm3/min)	TWR (mm3/min)
2	50	41.58	0.008	0.02651	0.0006667	3.465	74.4047619
2	100	39.69	0.007	0.0253	0.0005833	3.3075	65.10416667
2	200	39.69	0.005	0.0253	0.0004167	3.3075	46.50297619
10	50	281.61	0.052	0.17953	0.0043333	23.4675	483.6309524
10	100	292.95	0.016	0.18676	0.0013333	24.4125	148.8095238
10	200	219.24	0.009	0.13977	0.00075	18.27	83.70535714
18	50	529.2	0.074	0.33737	0.0061667	44.1	688.2440476
18	100	442.26	0.063	0.28194	0.00525	36.855	585.9375
18	200	455.49	0.017	0.29037	0.0014167	37.9575	158.110119

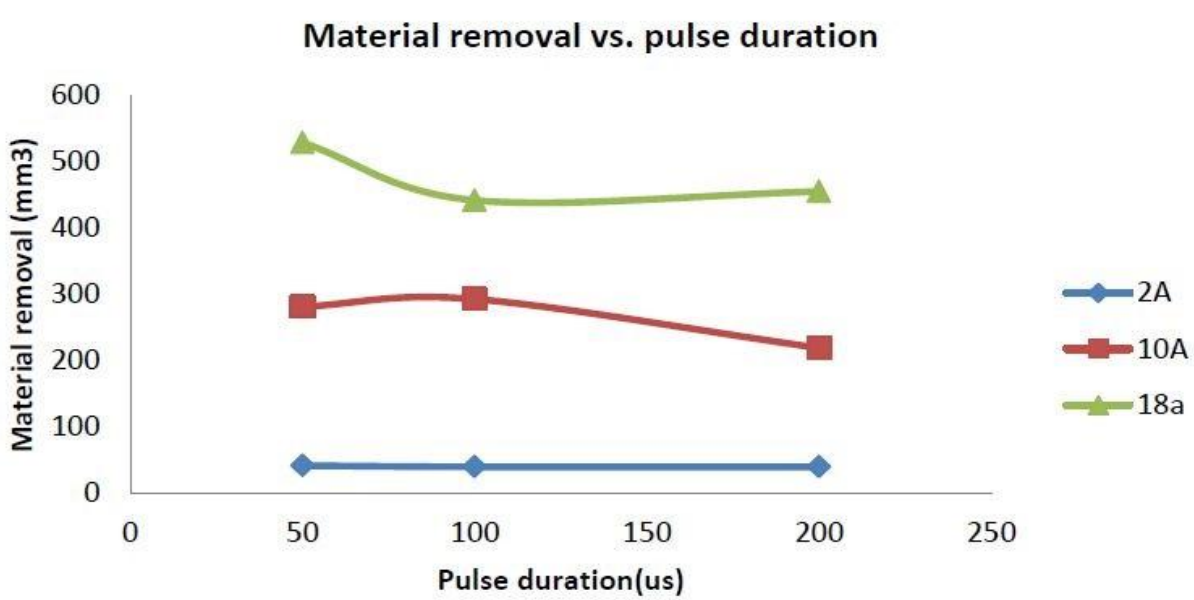

Fig.16. Effect of pulse duration on material removal rate.

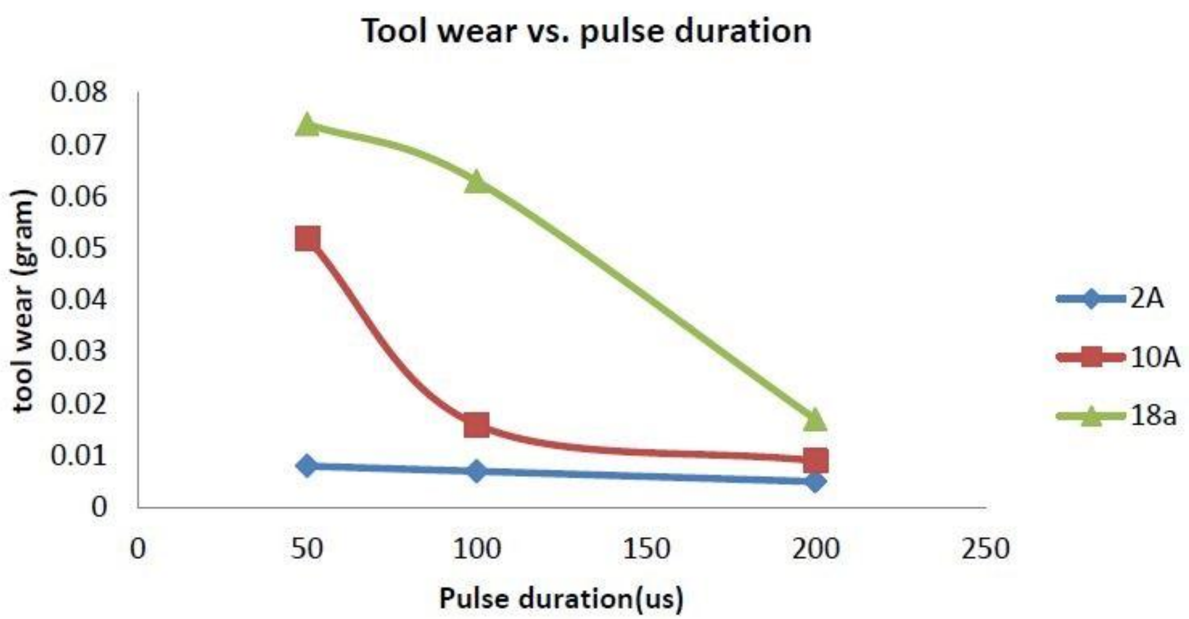

Fig.17. Effect of pulse duration on tool wear rate.

From the above graphs it can be found that with increase in pulse duration but for the graph for 2A current seems to be parallel to the horizontal axis. But it is actually not. The material removal and tool wear increases but not significantly as shown in the figures above.

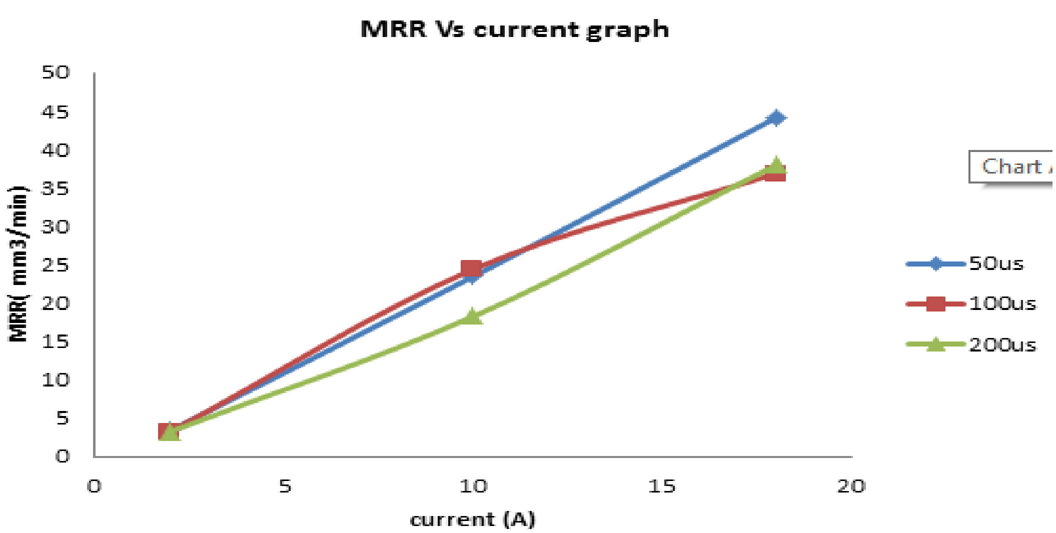

Fig.18. Effect of current on material removal rate.

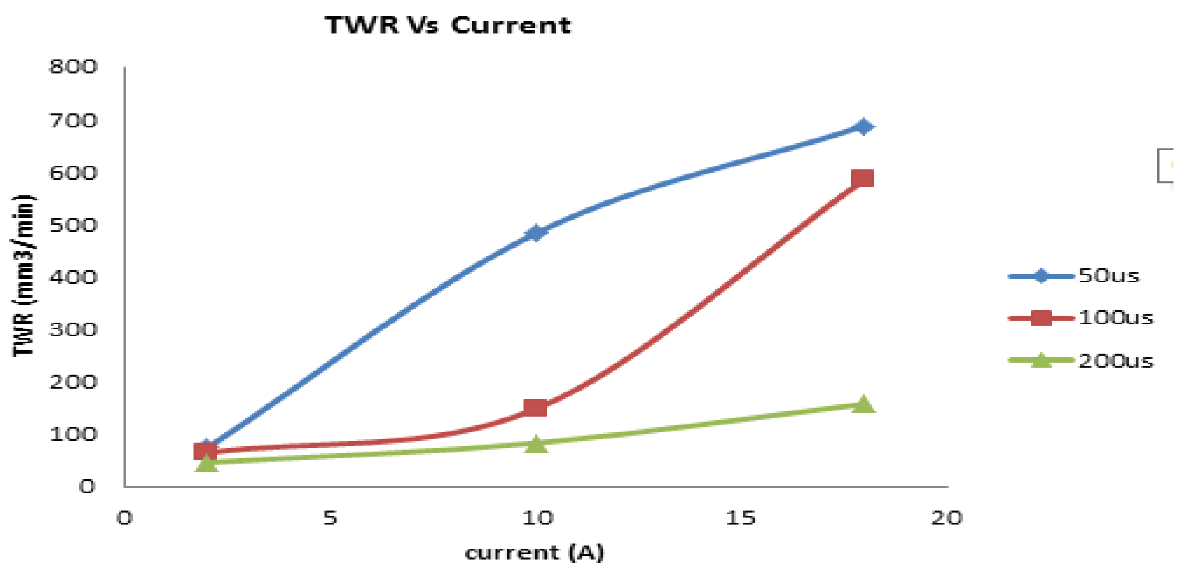

Fig.19. Effect of current on tool wear rate.

From the graphs it is observed that with increase in current the material removal rate (MRR) and tool wear rate (TWR) increases.

The energy responsible for this material removal and tool wear also varies according to different input parameters. The tabulation for this energy and fraction of energy with respect to primary energy is shown in the following table.

Table. 4 .Energy responsible for MRR and TWR and its fraction w.r.t. total energy

Ip(A)	Ton(us)	E(total)(watt)	E(MRR)	E(TWR)	%E(MRR)	%E(TWR)
2	50	70	0.4	0.057	20	2.85
2	100	80	0.383	0.0498	19.15	2.49
2	200	90	0.383	0.0285	19.15	1.425
10	50	400	2.681	0.3705	26.81	3.705
10	100	450	2.83	0.114	28.3	1.14
10	200	350	2.101	0.064	21.01	0.64
18	50	810	5.07	0.52	28.167	2.89
18	100	630	4.23	0.44	23.5	2.44
18	200	720	4.35	0.118	24.167	0.656

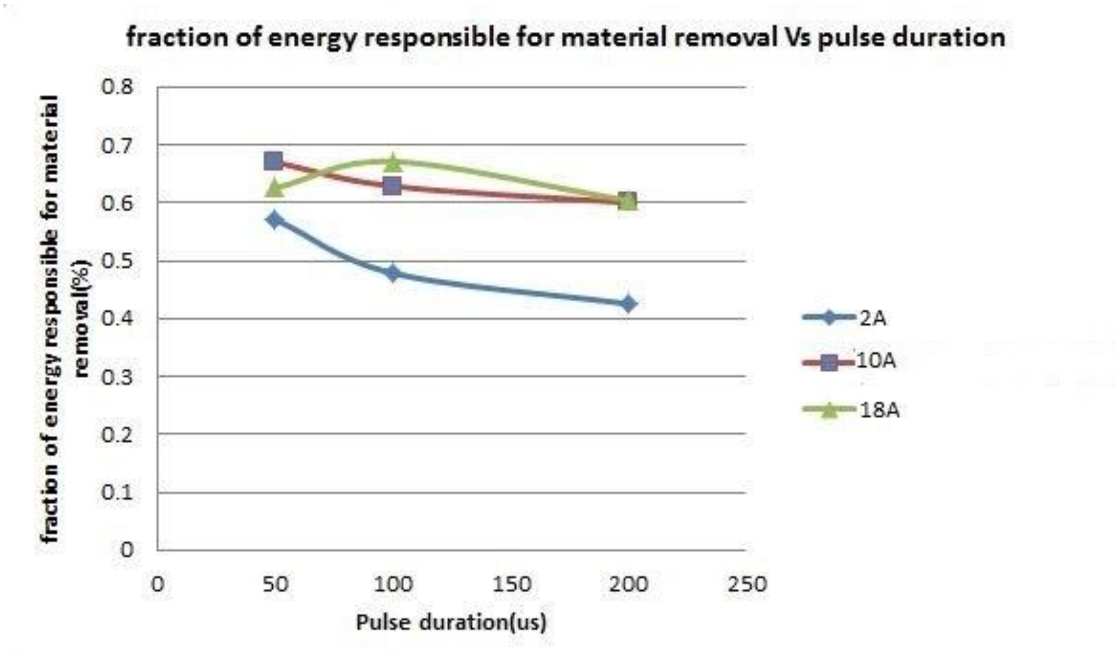

Fig.20. variation fraction of energy responsible for MRR with pulse duration

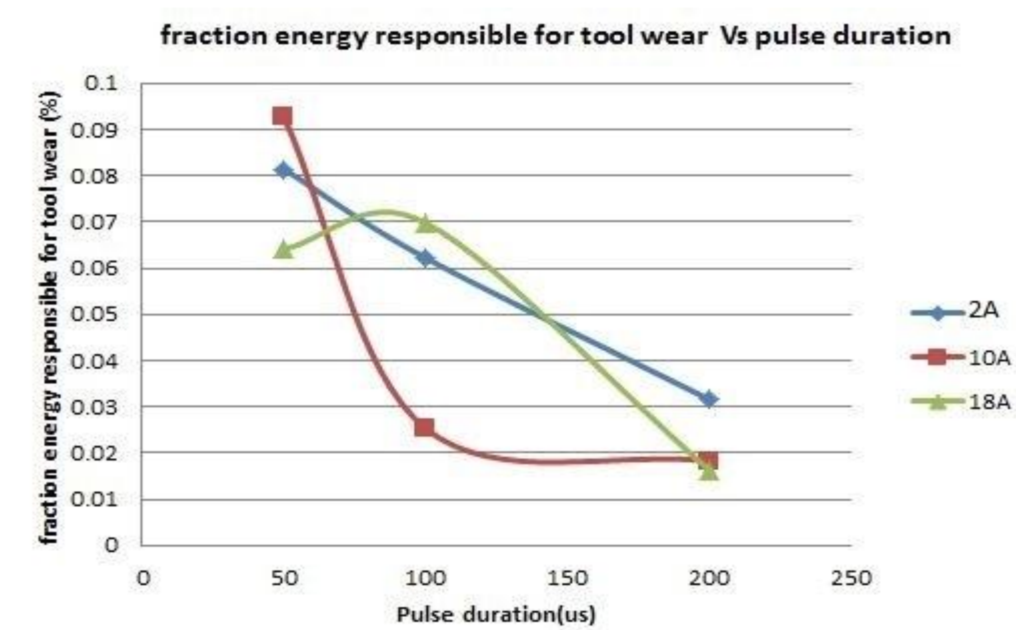

Fig.21. variation fraction of energy responsible for TWR with pulse duration

It is observed that with increase in pulse duration the energy transferred for material removal and tool wear increases undoubtedly but the fraction of primary energy transferred for material removal and tool wear decreases. So in order to prevent tool erosion as our problem statement, we need to operate at higher pulse duration and the current value should be optimum. From the above graphs it is observed that for higher current, in our case 18A, first the MRR and TWR increases and then it decreases drastically. So if we choose a higher value of current we need to perform the operation with pulse duration high. The reason for the less MRR and TWR at higher pulse duration is the energy density, i.e.; with increase in discharge time, the energy density in the plasma decreases which finally affects the MRR and TWR.

The response for surface roughness is also measured and is shown in the table below and its variation is depicted in the graphical form.

Table.5. Reading of surface roughness values for different input parameter.

Ip(A)	Ton(us)	SR
2	50	3.14
2	100	4.2
2	200	4.4
10	50	7.8
10	100	9.4
10	200	7.6
18	50	11
18	100	11
18	200	16

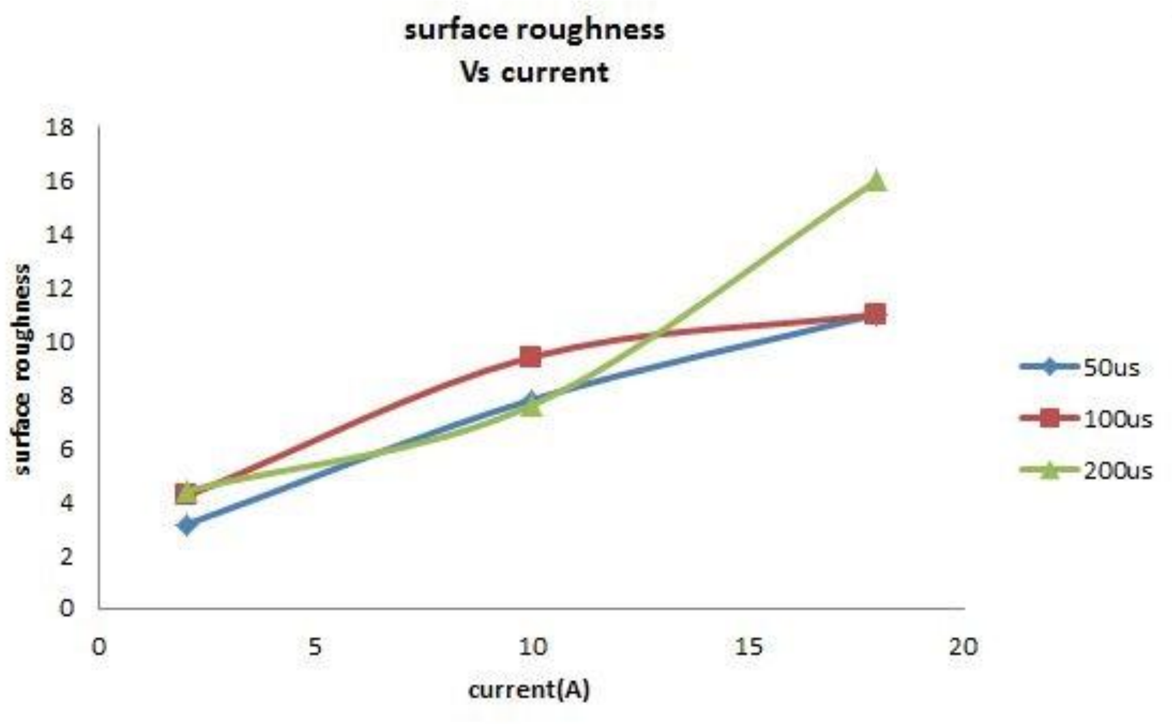

Fig.22. variation of surface roughness with current.

From the graphs it is inferred that with increase in current he surface roughness also increases.

Observations made on tool:

1. After carrying out total of nine experiments, it was found that the cross sectional area of the tool has decreased by 8.6 mm^2. It was difficult to find the reduction in cross sectional area after each experiment
2. The material removal from the periphery of the tool is more than that of the center portion. This is because when the tool is penetrating into the work piece, the material is also removed from the vertical walls of the tool leading to more material removal from the periphery.

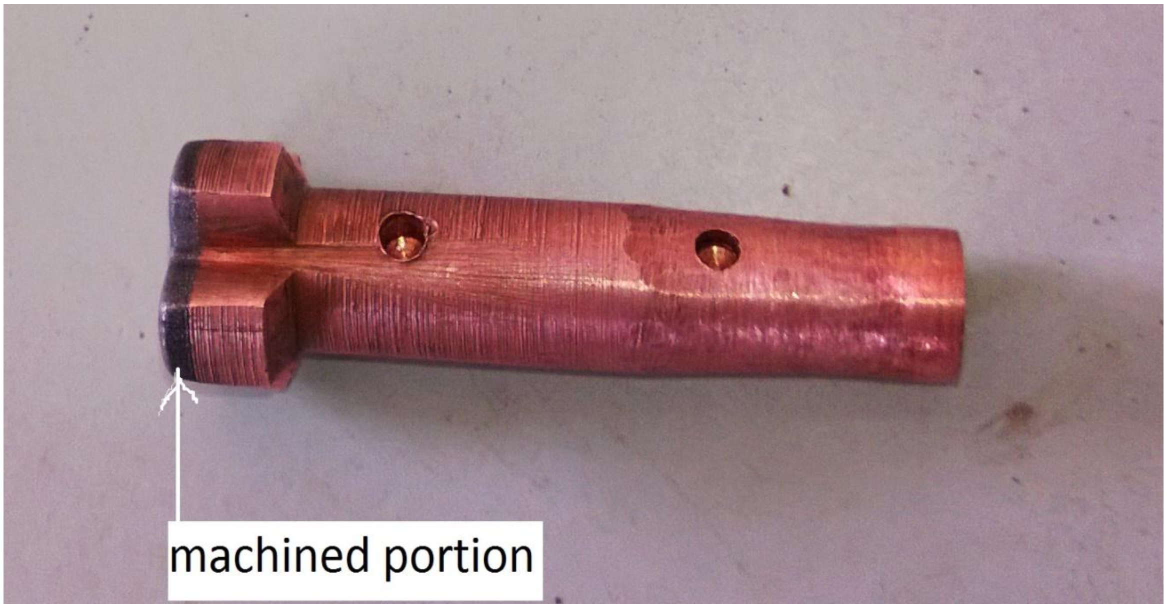

Fig.23. figure showing the vertical portion involved in the machining operation.

3. The edges which were of sharp nature initially became a little filleted. This is due to the reason that the vertical portion is also involved in machining operation.

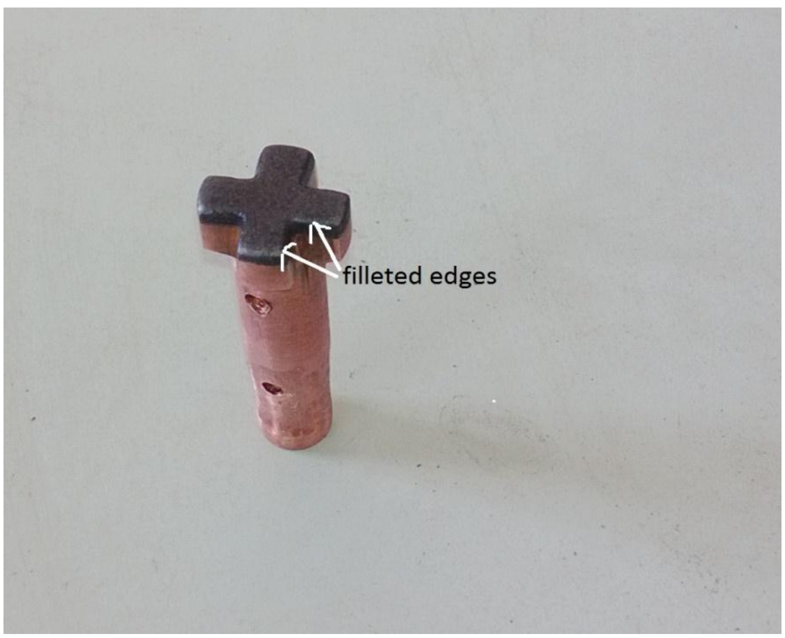

Fig.24. figure showing the filleted edges due to more material removal at periphery.

Observations on work piece:

The different photos showing the profile of the impression for different input parameter are shown in the following figure.

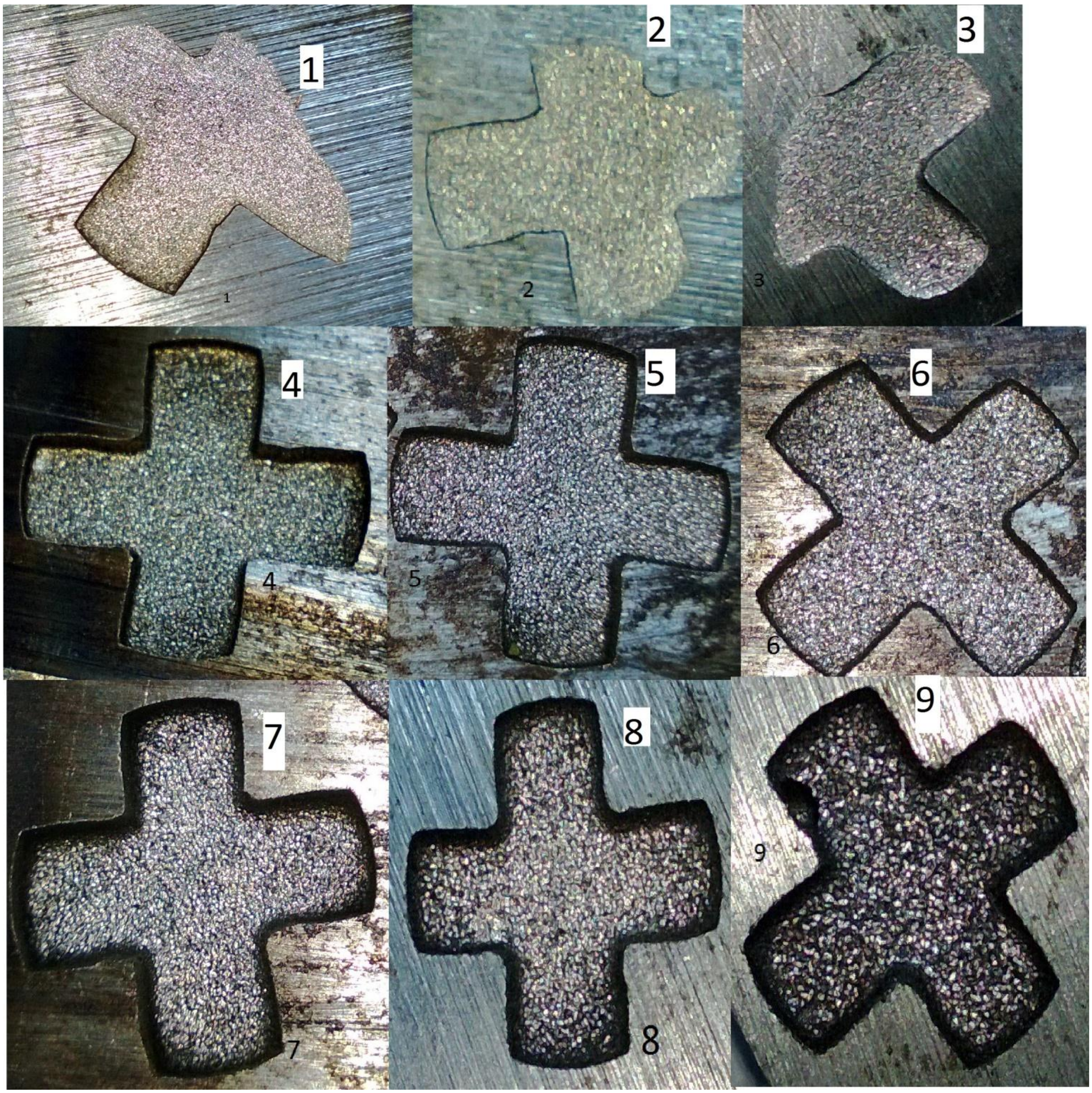

Fig.25. the view of machined surfaces for total 9 experiments.

Optimization of the energy responsible for MRR and TWR:

Grey relationship optimization was performed on the fraction energy responsible for material removal rate and tool wear rate. The following curves were obtained.

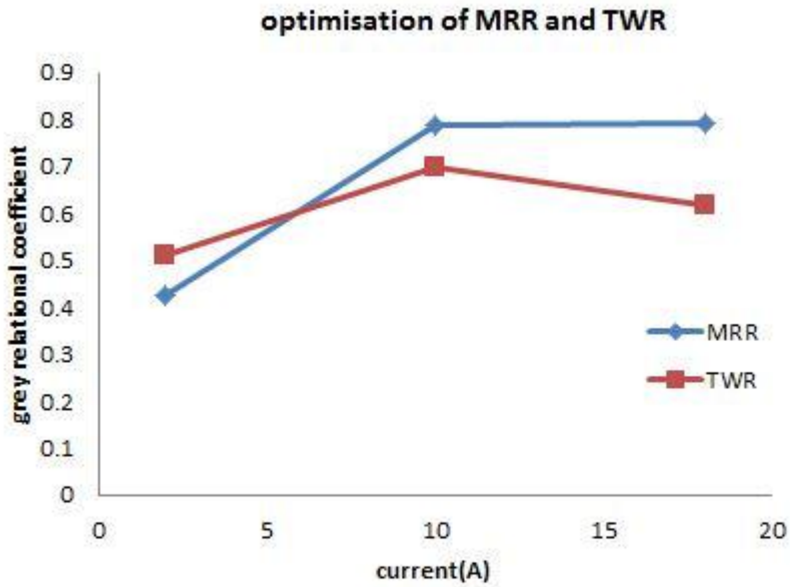

Fig.26. variation of Grey relation coefficient for MRR and TWR with current

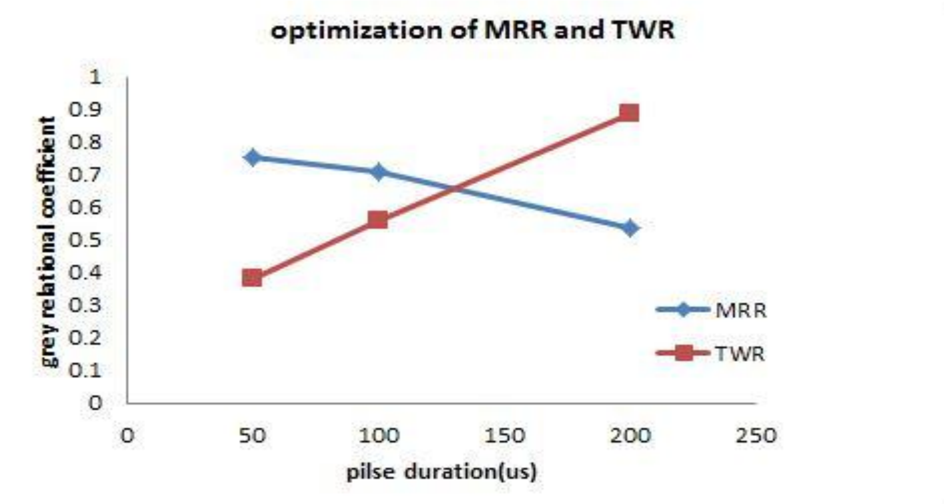

Fig.27. variation of Grey relation coefficient for MRR and TWR with current.

Optimization was done with respect to current as well as pulse duration for both MRR and TWR. From the figure above it is found that for maximum MRR, current should be 18Amphere and pulse duration be 50us. Similarly for minimum TWR, current should be 10Amphere and pulse duration be 200us in the given experiment.

CHAPTER 06 CONCLUSION

The above study was solely dedicated to calculate the fraction of energy transferred to each of tool, work piece, dielectric, and energy responsible for material removal and tool wear. Thus the conclusions of the above research are as follows:

1. Input energy is a function of current, pulse duration and voltage.

2. Fraction of total energy transferred to work piece and tool are function of current and pulse duration. Generally this fraction increases with increase in current or pulse duration. The fraction of energy transferred to work piece varies from 8% to 19% and that for tool is 18% to 24.12%.

3. For low current maximum energy is transferred at low pulse duration as in our case with increase in pulse duration the fraction energy transferred to tool decreases . but for higher current maximum energy is transferred at high pulse duration.

4. Energy responsible for material removal and tool wear decreases with increase in pulse duration but increases with increase in current. Same trend follows for material remival rate and tool wear rate.

5. Surface roughness increases with increase in current as well as pulse duration.
6. All the variations shown here can be utilized in the future while machining with EDM. If complex shaped impression is to be imprinted on the work pieces then the optical parameters from the study can be used to get the suitable result.

Future scope

Experiments should be carried out using different combination of tool and work pieces. Also input parameters can be taken differently in order to find the energy distribution to each and every portion of the set-up.

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