EXPERIMENTAL DETERMINATION OF APPROPRIATE TOOL MATERIAL FOR MACHINING DIFFERENT WORK MATERIALS BY EDM PROCESS

A project theis

by

ASHOK KUMAR SARDAR

Submitted to the department of Industrial and Production Engineering, Bangladesh University of Engineering and Technology, Dhaka in partial fulfillment of the requirements for the degree of MASTER OF ENGINEERING in Industrial and Production.

DEPARTMENT OF INDUSTRIAL AND PRODUCTION ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING & TECHNOLOGY

DHAKA-1000

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ABSTRACT

The present work deals mainly with the machining of conductive work materials by direct application of electric sparks. Electro spark apparatus is made of a circuit including both the work piece and the tool as electrode, continuously spaced apart and mutually insulated from each other except during a high frequency sequence of separate time spaced unidirectional spark discharge caused to take place between them. Electrical discharge machining was performed on materials copper, brass, stainless-steel, mild-steel and cast-iron , using the same type of materials as electrodes. The effect of process pramaters and variation of time on material removal rate (MRR), surface roughness(SR), recast layer (RCL), tool wear, accuracy of machining and surface finish were studied. It was observed that though material removal rate increases almost linearly during in the machining process, surface finish decreases due to re solidification of micro chip on the surface to form a recast layer. No crack was found in the recast layer in the case of brass and copper electrodes and softened heat affected zone was observed below the recast layer. Machining time as well as power control the material removal rate (MRR), accuracy of machining, and the depth of the recast layer but current plays the dominating role on surface finish in the E.D.M process.

CERTIFICATE

This is to certificate that this work has been done by me and it was not submitted else where for the award of any degree or diploma or for any publication

Supervisor

Author

To
My
Parents

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NOTATIONS

C = Capacity in micro farads

D = Dia of hole in mm.

E_g = Potential at terminal of condenser and spark gap and also appears as a counter emf in charging circuit

E_s = Potential source

I_c = Condenser charging current

L = Depth of hole in mm.

R = Resistance in ohm.

R_a = Roughness value in (μm)

R_c = Resistance of charging circuit

T = Time in min.

T_f = Fatigue allowance, min.

T_h = Handling time, min.

T_m = Machining time, min.

T_p = Standard time per piece, min.

T_s = Servicing time, min.

V = Volume of material in mm^3.

CHAPTER ONE

1.1 GENERAL INTRODUCTION

The country has launched a program of intensive Industrialization including manufacturing of machine tools spare parts for agricultural sector, micro electronics and the transport sector. The government, semi govt and private sectors have made a good head way in developing the industrial potentialities. Although most of the sectors are faced with numerous problems the industrial sector, is at present capable of meeting a major portion of the country's demand in these field. One of the major problems which is faced by the machine building industry is a shortage of technical knowledge for proper and economic operation of the EDM machine tools. This is a hindrance to the manufacture of sophisticated parts. Our country limited facilities of EDM machine but are available in BITAC, BOF, and BUET. In these factories a small number of engineers and almost no worker are aware of the appropriate tool materials in the EDM machining process. Without technical knowledge achievement of economic development in industrial production is almost impossible. In the factory the whole metal removal process is based on assumption due to lack of proper technical knowledge in this field and also equipment facilities (Generally copper electrode is used which is based on assumption).Thus development of new economical and scientific methods of metal removal process for different combination of work and tool material pairs is beyond the scope of the factory. In practice the values of the EDM variables are determined either by mere experience as usually done by EDM operators or selected from the available Engineering tables. None of the methods takes the process constraints into consideration and merely depend on the personal experience of the employed personnel and hence lead to values which are for away from the economic values. It results in low production rate and high machining cost which is undesirable for the factory. Therefore any means to improve this situation is of direct concern to all.

To improve upon this condition, it is necessary to study the underlying principles of metal removal rate and electrode wear and to employ more effective tool electrode for the EDM process. This will enable to raise productivity, to increase machining accuracy and surface finishing and to machine most economically. The primary purpose for machining parameters corresponding to optimum conditions, the optimization is performed with respect to an objective function which may be

a. *The machining cost.*
b. *Material removal rate (production rate) and*
c. *A suitable combination of these two prameters.*

So optimum results for metal removal rate operation interm of cost, metal removal rate and time is of major importance to the factory.

Selection of appropriate tool has been recognized as a major factor governing the economics of the metal removal rate.Experiences gained over the material (copper, brass, stainless-steel, cast-iron, mild-steel) have led to the determination of appropriate tool for the different cases at a given machining time, so with a view to using the minimum cost and the appropriate tool for metal removal rate by EDM process in factory, this experimental study has been conducted. In this case five locally available materials have been chosen as work materials. The task is to find out the appropriate tool material for this work materials.

1.2 LITERATURE REVIEWS

As the world is advancing forth technically in the field of space research, missile and nuclear industry,very complicated and precise components having some special requirement are demanded by these industries. The challenge is taken by the new developments taking place in the manufacturing field.After the 2nd world war many new materials and unconventional method of forming difficult to machine metals have evolved which are being put to commercial use with time. The term unconventional is used in the sense that the metals like hastalloy, nitralloy, nimonics etc. are such that they cannot machined by conventional methods but required some special techniques. Electro-discharge machining is among the earliest of the nontraditional manufacturing process (N.T.M), having had its inception 50 years ago in a simple die sinking application.

There are two major types of EDM :

(1) Die sinking EDM and
(2) Wire EDM

Die sinking EDM is traditionally performed vertically but it may also be conducted horizontally.While wire EDM remains in the main stream of notraditional machining (N.T.M) techniques, it has been greatly refined since the 1940's with the advent of transistorized pulse generators, planetary & orbital motion techniques, C.N.C & adaptive Radio Frequency (RF) control, 5 axis C.N.C WEDM is now routinely employed in complex 2-dimensional contour machining job.

Research in the metal remove by E.D.M process had been carried out by U.S.S.R scientist B.R Lazarenkov(1) as far been as 1946, although fundamental theories have been developed during the past decade. Beginning in 1930 & through 1960 several contribution were made toward understanding the mechanics of metal removing process work piece accuracy, surface finish & environmental of the working zone.

In 1947 D.T Vasillev(2) in his work "Electronic Control of Electric Spark Machining Processes" stimulated considerable experimental work in Machining process. His work emphasized the material removed from machining surface. However from that time until 1960 the development led more toward producing empirical data that contributing to theoretical analysis. Fundamental research on the metal remove mechanism has been continued since 1945 and has been influenced by similar researchers. In 1949 Koncz(3) confirmed the role of the electrode in machining processes and presented theories on the mechanics of metal remove and surface finish of the machined part. Considerable stimulus is given to the theory of "Eelectro-Erosion of Metal" by S.L. Mandelshram and S.M. Raiskii(4) in the same year. These researcher also explained the mechanics of removal and the interrelated effect of tool electrode dielectric fluid, and surface finish.

In the year 1953 American scientist C.R Alden(5) described of the progress of EDM machine which was made by the direct application of electricity to work materials for machining purposes. He emphasised on the potentialities of these process for the future development and also explained the removal of a substantially constant particle weight of the work piece material per spark, as the effective electrode has substantially no effect upon the frequency of sparking on the mass of particles removal per spark. The greater the effective electrode area, the slower the material remove rate will progress. Regarding many reports on metallurgical effects on the both work piece and tool electrode, testing method etc., have been presented by many researchers.

In 1956 Wilms and J.B. Wade(6) presented surface & metallurgical effect in EDM and these were also represented by others. In a comprehensive review, Bucklow and cole(7) emphasised the role of the metallurgical aspects and categories of existing investigation on the nature of Electro-discharge machined surfaces. They followed the investigation techniques of optical metallography, electron micro copy, and mechanical temperature measurement.

In 1958, Aleksandrov(8), and Aleksandrov and Zolotykh(9), Goldsmidt(10), Barash(11), and LLoyd and Warren(12). investigated the residual stresses, due to EDM effect on the machining surfaces. Aleksandrov & Zolotykh(9) indicated that surface finish and depth of surface layer affected depended to a considerable extent upon the pulse duration, hence it is expected that residual stresses would be so influenced by pulse duration. M.M. Barash(13-14) was mainly concerned about the effects on mechanical performance notably fatigue life but spark-turned specimens of tool steels showed a reduction in endurance limit when compared with specimens which had been turned conventionally to

give the same surface finish. However, the detrimental effects of the tensile residual stresses are found to be minor when compared with the effects of permanent damage, such as cracks and micro-cracks.
In 1970 Oliver(15) Suggested new methods involving electron emission, proton annihilation and nuclear resonance Again the value of these method in the precise determination of residual stresses in yet to be established.

In 1970 F.J Demaine and B. Schneider(16) carried out experiments on metal removal principles and established a relationship between metal removal rate and melting point. G. Bellows(17) 1972 also developed the relationship of surface finish with material removal rate. In 1972 J.R. Crookall and B.C Khor(18) showed how high tensile residual stresses are generated by EDM process, and work pieces material & particularly its thermal properties, influenced the distribution of residual stress.

In 1977 L Houman(19) estimated the time required in the EDM process and showed relationship between material remove rate (MRR) and time.

The EDM technology significantly advanced during the late 1980's owing to two major development one improvements to the performance of the EDM process & other increased level of automation. The role of electrode on the new cramics explained by W. Kubota, Y. Tamura, H. Tsuchiyia, M. Miyazaki(20) in 1986. These groups also concluded that lower frequency, higher current, low gap voltage and positive polarity can be used for roughing cuts.

1992 G.H.D. Banadeki, V.S.R. Murti, V.M. Shamraj(21), found out effect of gap flushing which in highly significant for improvement in machining rate and accuracy in the form of reduced over size, side taper, bottom surface flatness error and corner radii can be expected, The recast layer in also more uniform in thickness.

K.P. Rajurkar and S.R. Nooka(22) 1994 carried out investigations on surface finish by EDM process and showed that finish has obtain about 0.3 μm Ra and with an appropriate set of parameter Ra <0.2μm can be achieved. In the same year P.K Madan and R Sagar(23) work on the composites materials by EDM process and find out the material remove rate (MRR) and wear ratio (WR) and surface finish (SF) as an objective function for selection of appropriate electrode. He also described the effect of large current density, on the composite material including melting of the surface.

1994 T.Uematsu, K. Suzuk, T. Yanase, T. Makizaki(24) on their work "Fine Profile Turning of Metal Bonded Diamond Wheels by EDM on NC Profile Grinder" showed that wire electrode method is more suitable than rotating electrode method.

The present work attempts to selected the appropriate tool material for machining different work material (such as copper, brass, mild-steel, cast-iron and stainless- steel) on the basis on the material removal rate (MRR) surface finish (SF), cost of machining and to establish relationship between metal removal rate (MRR), wear ratio (WR), and surface finish with time. Attempts have been made in this section, to present a comprehensive list of the tool material so far used, find out the maximum metal removal rate for various combinations of work and tool materials

1.3 AIMS AND OBJECTIVE :

The aim of the present work is to identify the proper tool and work material combinations in EDM process, which would ensure minimum cost of machining and required quality of machined surface.

To achieve this aim the following objectives are set on the present work.

(a) To determine the metal removal rate for different combinations of work and tool material pairs.

(b) To determine the average surface roughness and size of the micro cavity formed on the machined surface for different job tool material combination.

(c) To study the micro-structure of the machined surface to determined the recast layer formed in the cases of different work tool material combination.

(d) To establish graphical relationship of metal removal rate, tool wear and tool cost, average surface roughness of the machined surface at a given cutting condition with a view to determined the appropriate tool materials for machining different work material by EDM process.

1.4 ORGANIZATION OF THE PROJECT THESIS WORK :

This project work is organized as follows.

Chapter 1 presents a literature views on EDM process. In 2 chapter the principle of EDM process is presented. The 3rd chapter describes the various aspects of the process. Chapter 4 presents the machine setup and the methodology of data generation. The 5th chapter describes the result and discussion. Chapter 6 presents the cost analysis. Conclusion and recommendation for future research are presented in Chapter 7.

CHAPTER TWO

2.1 PRINCIPLE OF EDM PROCESS :

Fig-1 Shows in simplest diagrammatic form a sparking system which is used in the earliest electro-spark machining. Such systems are characterized by an energy storage. Source illustrated by the condenser C, Which may be charged at a controlled rate from a source of d-c potential. The storage source has its positive terminal connected to the anodic (work piece) electrode, and its negative terminal connected to the cathodic electrode(tool). The length of the spark gap can,(0.01 to 0.5mm.) be regulated between the tool and the work material by a servo motor which is actuated by the difference between a reference voltage and the gap break down voltage, as a result tool advance s towards the work piece. This are provided for continuously maintaining at least the active portions of the electrodes inundated in a bath of dielectric hydrocarbon oil like Kerosene. This also are provided for circulating the dielectric through the spark gap to flush continuously therefore the particles of electrode material as rapidly as these are dislodged.

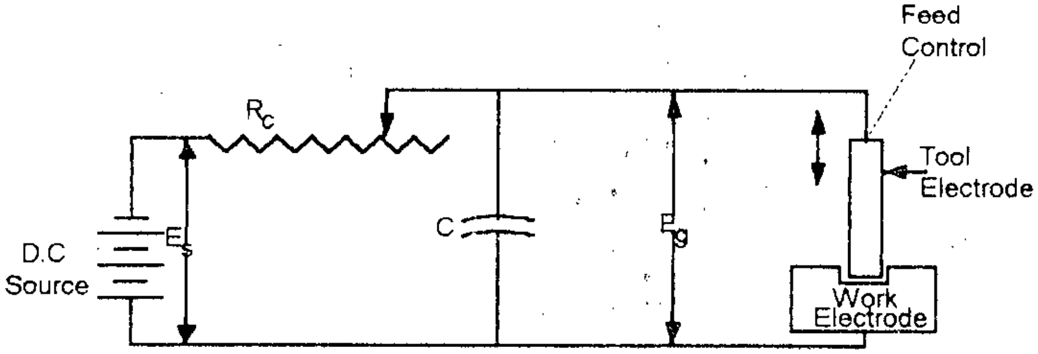


Fig.1 : Diagram of sparking system illustrating earliest known circuit used in electrospark machining

Upon energizing the condenser charging circuit and the gap regulatory means, the potential on the condenser normally will rise to a value adequate to break down the dielectric within the spark gap. If too widely spaced, the gap regulating means will sense the resulting over voltage condition at the gap and cause the armature of regulator (servo motor) motor to move the electrodes more closely together. If the electrodes happen to be in contact or too close together or bridged by particles previously dislodged from the electrodes, the resulting under voltage condition at the gap will cause an increase in electrode separation.

In short, the regulatory means, by constant adjustment of the spark-gap length, maintains within narrow limits a predetermined potential which must be applied to the gap to institute ionization or electrical breakdown of the dielectric. When normally regulated, repetitive cycles of events occur in the system at high frequency each cycle culminating in the passage of a spark between the electrodes.

2.2 MECHANISM OF THE PROCESS :

2.2.1 Charge Accumulation:

As the condenser is connected continuously to the charging source and the spark gap will later be shown to be substantially non conductive following each spark, the condenser charging period begins immediately upon termination of each spark discharge between the electrodes. In the simplified schematic diagram in Fig.1 there is no certain control of the charging current which are effective particularly in the charging period. As to the schematic drawing shown it will suffice to say that at any instant during the charge accumulation period :

Ic = (Es-Eg) Rc in which

Ic = Condenser charging current

Es = Potential of source

Eg = Potential at terminals of condenser and spark gap and also appears as a counter emf in charging circuit

Rc = Resistance of charging circuit which in the presently simplified circuit may be considered to be with out inductive reactance.

At the beginning of the charging period of the quantity Eg is substantially zero and as a consequence, Ic then has its maximum value. As time permits the charge to accumulate, Eg asymptotically approaches Es and Ic similarly approaches zero. However if the spark gap is adjusted to its normal operating length, discharge of storage C will be initiated while the quantity (Es-Eg) still has a appreciable value. Termination of the charge accumulating period is occasioned by initiation of the discharge period.

2.2.2 DISCHARGE PERIOD :

As the potential Eg increases, the dielectric in the gap becomes highly stressed . At a point in the rise of Eg the dielectric will be broken down electrically. At this instant the resistance of the spark gap which had there fore been substantially non-conductive, changes within an almost infinitesimal time to a value which is very low. Then the gap has become ionized, thus rendering it conductive and millions of electrons are developed in each spark. During sparking period voltage immediately falls and it again starts rising as shown in Fig.2, 3.

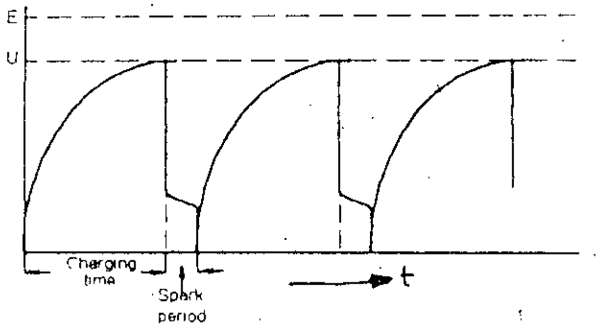


Fig. 2 :

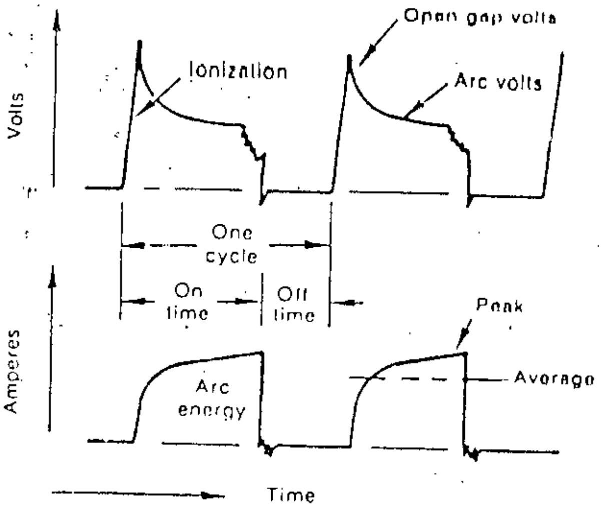


Fig.3: Simplified voltage and current traces

Immediately upon ionization of any path through the dielectric in the gap, the discharge rate there through becomes so great that the rate at which energy is admitted to the condenser via the charging circuit sinks into complete insignificance by comparison. As a consequence, the discharge period is very much shorter than the charging period. The falling potential on the condenser quickly drops to such a value that ionization of the spark path through the dielectric can not be maintained. The inundated gap then again resumes its very low conductivity, causing the discharge rate to be come insignificant in relation to the current Ic and a new period of change accumulation is instituted. The charging time will follow the basic equation T=RC in which the time(T) will be given in seconds if the resistance is expressed in ohms(R) and the capacity(C) in micro farads. From the above discussion some rules may be governing during dishrags period in E.D.M process are:-

1. There is no current passing through the dielectric fluid in the sense of a direct flow of free electrons. the motion of the electron which permits a continuos flow of heat from cathode to anode.

2. The change at the cathode must involve a transfer of the same number of electrons through the anode, as a result, anode also changes its polarity.

3. The polarity of the material in the process will also be changed, as does the change of metal removal rate (M.R.R), work to wear ratio and surface finish as shown in Table 1. (27)

TABLE - 1 : EDM polarity of material

ITEM	**Electrode (tool)**	**polarity**
	Negative	**Positive**
Metal removal rate	Medium to high	Medium to low
Work to wear ratio	Medium	High
Surface roughness	Good to rough	Good to excellent
Work piece material	**Electrode material**	**Electrode polarity**
Copper	Brass	Negative
	Stainless-steel	Positive
	Mild steel	Positive
	Cast iron	Positive
	Copper	Negative
Brass	Brass	Negative
	Mild steel	Positive
	Copper	Negative
	Cast iron	Positive
	Stainless steel	Positive
Mild steel	Cast iron	Positive
	Copper	Negative
	Mild steel	Positive
	Stainless steel	Positive
	Brass	Negative
Stainless steel	Mild steel	Positive
	Cast iron	Positive
	Brass	Negative
	Stainless steel	Positive
	Copper	Negative
Cast iron	Copper	Negative
	Stainless steel	Positive
	Mild steel	Positive
	Cast iron	Positive
	Brass	Negative

2.3 MATERIAL REMOVAL RATE (MRR)

The effective area of the spark gap, is initiated at the point in the gap surface where the dielectric stress is greatest. Usually this is the point where the distance of separation is least. As the area of this point is substantially zero, the streaming of electrons and positive ions, from the dielectric material through this almost infinitesimal area, results in a current of very high density, this density is limited only by the availability of ions. Because the resistance of an ionized path through the dielectric is very low , and the current density through this path is extremely high. This may be of the order of 100, 000, 000, ampere per sq. in.

The result of a rupture or electrical break down of the dielectric in the spark gap there fore in distinctly not a general ionization of the entire gap but is limited to a single path which is of almost infinitesimal area. As a result of finite conductivity of the work piece material a very high electric field gradient occurs in the materials of the electrodes about the points of impingement of the electric spark defined by the termini of this path of almost infinitesimal area. This field acts upon the positive ions of the material of the electrodes immediately adjacent the termini of the spark path. On the anode (work piece) this material is placed in tension and because the forces of the electric field exceed the rupture strength of the material, however great this may be, particles of the anode are torn off and move through the dielectric toward the cathode. (Fig. 4,5)

About the end of this spark path which terminates at the cathode, the material is placed in compression by the electric field, particles do not experience the same tendency to be dislodged and consequently, the material removed from the anode in greater in volume than that removed from the cathode.

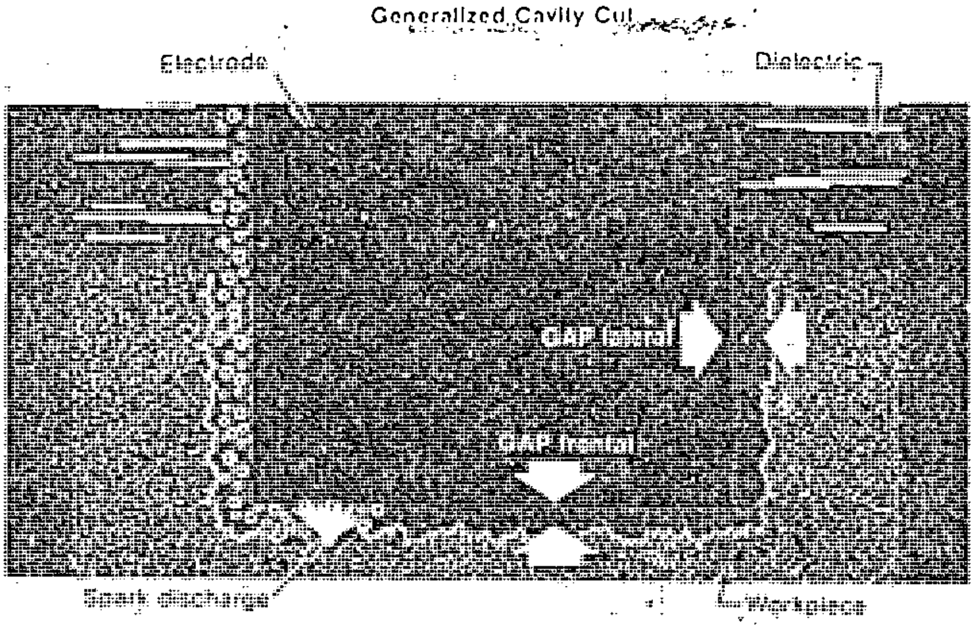


Fig. 4 : Generalized cavity cut

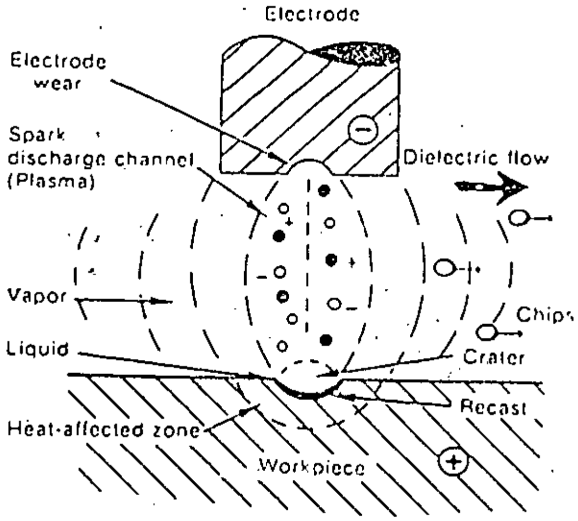


Fig. 5 : Simplified spark discharge

It is clear that the almost infinitesimal time immediately following ionization of such a path through the gap is of the utmost importance in metal removal by the Electro spark method and it is preferable to cause the electric discharge to have the highest possible intensity by completing it in the shortest possible time than to expend an equal amount of energy at a lower rate over a longer period of time.

Particle dislodgment is the result of forces mechanically applied. The effect of heat as in inevitable associated with the passage of a spark which at most has a duration of form a fraction of one to a comparatively few micro second, if itself has an entirely negligible effect upon particle removal. No evidence has been found that removed particles achieve a temperature remotely approaching the molten state in process of removal. photo micro graphic studies of the work piece surface shown close agreement with surfaces fractured by mechanical means. None indicates the presence of heat as being contributory to the fact of particle removal.

After the resistance of the spark gap has been so greatly reduced as a result of initiation of ionization, every avoidable resistance or inductance in the condenser seen and its associated discharge circuit becomes important for the reason that resistance serves to limit the maximum current flow through the spark gap and inductance serves to limit both the maximum current and the maximum rate dI/dt by which this maximum current may be achieved

2.4 PRACTICAL APPLICATIONS :

This process is used for cutting any electrically conductive material and is particularly adapted for machining irregular slots or cavities, smaller components usually highly complicated, multi function parts which are used in the field of micro electronics, medicine, aerospace and to given any intricate shape or profile. The scope of EDM applications extends from 0.02 inch (0.05 mm) diameter holes to 50 ton (45 metric tons) automotive die cavities. Because there in no physical contact, good structures can be cut successfully. Three dimensional cut can be performed due to electrode is fed into the work piece. Because the sparks focus first on peaks and corners, burr-face cutting course.

This process is very useful for making hole of nozzles, other holes, like pin hole, any shapes, profiles and embossing, engraving operations on harder materials. Internal threads and internal helical gears can be cut in hardened materials by using a rotary spindle and suitable attachments.

It is also used for production work for special application where the oil retention properties of the work surface are important.

Narrow slots of 0.05 to 0.30 mm wide may be machined. Hexagonal cores and brittle material may also be cut easily. High strength and high hardness materials also be machined by this process.

It is very difficult to machine carbide by conventional process but by this process it can be machined easily. It can also machine ceramic carbide and other hard materials.

Surface finish obtained by this process in very good. As tool and work do not come in contact, so there is no cutting forces act in the work process and consequent error due to elastic deformation in eliminated and no burrs are formed.

Tool material need not to be harder than work material there for that material must be used which can be easily shaped. It is due to this reason that any complicated shape that can be made on the tool can be reproduced on the work piece.

In this process tolerances up to ± 0.04 μm can be obtained and finish up to 0.25 μm requiring minimum alternation when operation is perform.

And there is some limitation for any machining the work piece. In this case.

- Metal removal rate is slow.
- Machining costs are very high.
- Power requirement is very heavy.
- Reproduction of sharp corners is the limitation of this process.
- Surface cracking may take place in some materials due to their affinity to become brittle at room temperature especially when higher energy is used.
- Work piece metal must be an eclectically conductivity.
- Electrode must be shaped accurately for fast wearing of electrodes some times two or more electrodes may be required for one job.
- About 0.02 to 0.1 mm of re-solidified metal is left around the surfaces of the cut due to the heat involved in the process, which is not desirable if the work piece is to be subjected to stresses these after. These limitations lead to higher machining cost and power requirement than other process, and consequently to higher production cost.

CHAPTER THREE

DIFFERENT ASPECTS OF ELECTRO SPARK PROCESS

The most important factors are used for evaluating the appropriate tool material electrical discharge machining (E.D.M) process are:

(a) Material removal rate (MRR)
(b) Surface finish(SF) and
(c) Machining accuracy(MAC)

These technological characteristics dependence on the respective material removal rate, surface finish, machining accuracy parameters. The value of these technological characteristics cannot be unilaterally determined because they vary with the parameters of the machining method. Their repeatability is possible only if equal conditions are maintained during the machining process. The three above mentioned characteristics are discussed in this chapter

3.1 MATERIAL REMOVAL RATE (MRR) :

By material removal rate we understand the amount of material removed from the work piece over a unit of time. In the case of electrical discharge machining this is given in mm^3 /min. Sometime it is defined as the volume of metal removed per unit time per ampere. The principle of metal remove rate is lower in position of the operating conditions selector, the smaller the material removal rate and the better surface finish and vice versa. . Metal removal rates up to 80 mm^3/sec can be achieved and surface finishes to 0.25 μm can be obtained at very low cutting rates. For higher metal removal rate with good surface finish, roughing and finishing cuts with two electrodes are used.

The material removal rate depends on the following parameter.

(a) Electrical parameters of the machine tool
(b) Size of area of be machined
(c) Depth of cavity or hole to be machined
(d) Material of tool electrode
(e) Kind of dielectric fluid
(f) Size of electrode

3.1.1 ELECTRICAL PARAMETERS OF THE MACHINE TOOL:

These may be either operating current, operating voltage, frequency, duty cycle, capacity of charging circuit, supply voltage, polarity of material etc.

Current :

It is limited by the area of the electrode and by the gap between the electrode and the work piece. However finish gets poorer as amperage is increased. So low current flow in to the electrode should always be chosen.

Frequency :

At lower frequency metal removal rate is high but poor finish obtained. So, it also affect the material removal rate and surface finish.

Voltage :

It depends on the characteristic of dielectric fluid the work material and electrode. It should be just sufficient to ionize the dielectric fluid and cause spark to cross the gap and is rarely above 50 volts. So, the voltage constant during the operation should be maintained.

Duty cycle :

(Relative off on time of each pulse of electricity): Longer duty cycle increases metal. removal rate so it is necessary to increase this cycle.

Capacity of charging cycle :

High capacity of charging cycle increases more current which leads to maximum metal removal rate.

Polarity :

The change of polarity also change the material removal rate (MRR), work to wear ratio and surface finish (SF). These changes are shown in Table- 1.

3.1.2 SIZE OF AREA TO BE MACHINED :

This influences the material removal rate in such a manner that when machining small areas at higher positions of operating conditions for rough cut, the area to be machined becomes overheated, due to this fact. The stability of the machining process is disturbed and as a result the material removal rate is by approximately 30% lower than the assume value with increasing the area at the same operating conditions, the material removal rate steeply rises and after achieving the optimum value, gradually falls. The fall is caused by determined flushing of erosion products out of the spark gap. To increases the material removal rate with larger areas. It is necessary to apply forced flushing.

3.1.3 DEPTH OF CAVITY OR HOLE TO BE MACHINED:

Like the size of the area, mentioned above, the depth also affects the fall of material removal rate. It the depth of cut is high, then side taper occur, which is not acceptable. It is prevented by using forced flushing. and always try to low depth. which also leads better surface finish.

3.1.4 MATERIAL OF TOOL ELECTRODE

The selection of the proper metal or alloy for a tasks is an important part in the practice of EDM process. Because the material remove rate is influence by its physical properties such as thermal and electrical conductivity, specific heat and so on. The most suitable material for tool electrode is any conducting material generally brass, copper or alloy of copper or cast iron. These materials can be easily shaped to the required profile, where high accuracy and long electrode life are required, higher melting point materials such as copper tungsten, graphite or tungsten carbide are used . As the tool does not come into contact with the work piece, life of tool is long and less wear and tear takes place. The selection of proper tool material is influenced by the following criterion.

(a) Size of electrode and volume of material to be machined
(b) Surface finish required
(c) Desired tolerances
(d) Nature of cooland and applications and
(e) Cost. etc.

It has been experienced that certains materials are more suitable than others depending upon the material to be machined and the type of generator used.

The characteristic of tool material should be such that the wear ratio i.e. ratio of tool wear rate/metal remove rate is much less than unity and its hardness does not allow any deformation of the tool during the machining process. Since in that case the machine surface shape will be damage. It is interesting to note that the wear ratio for brass work is 0.5, for hardened plain carbon steel work 1.0 and for tungsten carbide work is 3.00 wear ratio has been reduced to 0.1 by using graphite anode with a pulse generator machine.

The performance of tool materials can be identifed by its material removal rate, low wear rate and ability to be accurately machined or formed.

The tool electrode for EDM constitutes the most important part and account for major cost. commercially EDM tool electrodes are made of any of the following three categories of material viz., metallic (electrolytic copper, tellurium or chromium copper, copper tungsten, brass, tungsten carbide, Aluminum etc.), non-metallic (graphite) and combination of metallic and non-metallic (copper-graphite) materials.

But in this project work the materials which are used as a electrode are :

(i) Copper (ii) Brass (iii) Stainless steel (iv) Mild steel (vi) Cast iron. The discussion of these five materials are given below :

(i) Copper :

It is a very important metal in industry as it has a great corrosion resistance property. It has good strength which is maintained all moderate temperatures. it is also ductile and can be worked into complex shapes. It having very high heat and electrical conductivity, due to these it can generally achieve better metal removal rates, less wear and fine surface finishes, and cost is also reasonable. Any shape can be produced by casting or machining and very complex features are formed by chemical etching or electro-forming.

It is most offend used when the finest surface are required. It has the capability of being polished to a fine surface finish , is possible being reflected on the machine surface without concern for the structure of the material .

Complicated shapes can be produced at low cost also. For these reason copper choose as compacted copper electrodes have been used for high production application. Fairly EDM tool electrode in the project work.

(ii) Brass :

Free machining brass is often used as an electrode material. It is available in most shops and is very easy to machine like as copper electrode. Brass in not often used as an electrode material for machining harder material like tungsten carbide because of its high wear rate. Brass has shown itself to be a good electrode material for same alloys of titanium under poor chip removal condition. It can be economically machined for many operations, also having good strength which maintained at moderate temperature. Heat and electrical conductivity also high. But less than copper. cost in same as copper electrode. This is the second choice as EDM electrode.

(iii) Stainless steel :

It is iron base alloy, having great resistance to corrosion. The properties of corrosion resistance is also having , maintain considerable strength at the moderate temperature. Heat electrical conductivity of this metal is lower than copper and brass. It is not easy to form into complex shapes like brass and copper electrode. But in the case of drill or hole shapes, can be use as a tool electrodes cost is reasonable and surface finish is approximately good. But not acceptable, gives slow material removal rates, suitable for doing parting line matching, Grating heat affected zones, but wear ratio is unsatisfactory. It is third choice as electrode.

(iv) Mild steel :

It is also iron base alloy, having maximum ductility properties but low electrical and heat conductivity and cost is low. It is easy to make a desire shape but limited use in E.D.M process.

(v) Cast iron :

It is also iron base alloy, having maximum amount of iron. Due to this properties it can not be easily shape into different shape by process, such as forging or hammering. Heat and electrical conductivity is very low than other four categories electrode metal remove rate is low, than other metals. Cost is also low. This metal also choose as a electrode in the project work.

The properties of the electrode are given in Table-2, which ensure the best suitable tool electrode in EDM process(26). Affect of melting point of the materials also shown in Fig 6.(27)

Electrical Discharge Machining—EDM

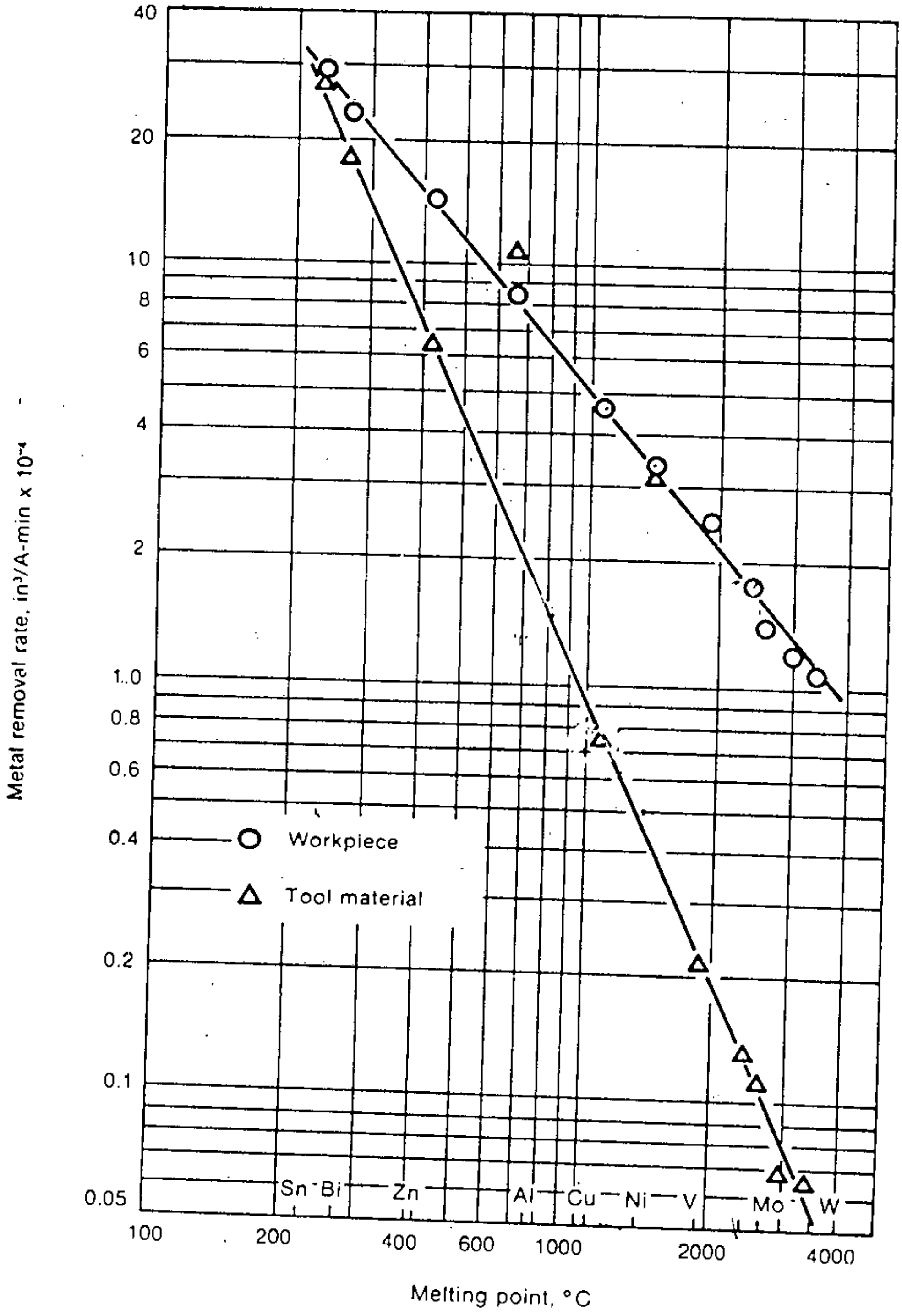


Figure 6 : Average metal removal rate versus melting point.

TABLE: 2 **Physical Properties Of The Materials**

Properties	Materials				
	Copper	Brass	Stainless steel	Mild steel	Cast iron
Melting point °c	1083	850	1535	1430	1250
Thermal conductivity cal/cm^2 /cm/°c/sec	92%	67%	19.33%	17.7%	15.33%
Electrical Resistivity at 20°c micro-ohms-cm	1.7241	3.39	8.2	8.7	9.1
Co.-efficient of thermal expansion per °c x10^{-6}	6.6	20.53	11	8.2	6.6
Specific heat cal/g°c	0.092	0.0928	0.107	0.1027	0.101
Electrical conductivity compared with silver	96.5	72	16.2	15	14.2
Specific gravity 20^{0}c, g/cm^3	8.9	8.24	7.9	7.85	7.8

3.1.5 DIELECTRIC FLUID :

In EDM rapid succession of discrete discharge are introduced between the electrodes, each discharge taking the path at which break down con be most readily achieved. For each discharge, the application of pulse voltage causes the field intensity at some local area with in the gap to produce sufficient current flow to vaporize and than ionize a very narrow channel with in the dielectric. The discharge then takes place as an electron flows towards the anode. The cathode is bombarded by ions from the decomposed dielectric and later still by ions and possible particles, from the vaporized anode. The anode is heated sooner and more rapidly than the cathode. Liquid dielectric assist in confining the discharge to a very narrow channel, thus maintaining a high current density, as also does the magnetic "pinch effect", for this reason the following function necessary for dielectric fluid.

- *(a) To helps in initiating discharge by serving as a conducting medium when ionized and conveys the spark. and also concentrates the energy to a very narrow region.*
- *(b) To maintains values of U (Discharge voltages)*
- *(c) To helps in quenching the spark, cooling the work, tool electrode and enables arcing to be prevented.*
- *(d) To carries away the eroded metal along with it.*
- *(e) To acts as a coolant in quenching the spark.*
- *(f) To insulate until required conditions are achieved.*

3.1.5.1 PROPERTIES OF DIELECTRIC FLUID :

For good functioning the following properties of dielectric fluid were required.

- *(i) The dielectric fluid should not evolve toxic vapors or gases during operations.*
- *(ii) It must be inflammable (high flash point).*
- *(iii) It should be chemically inert with respect to tool material, work material etc.*
- *(iv) It should be de ionized in the medium very quicking after discharge and should be an effective insulating medium during the next charging operations of the condenser.*
- *(v) It must have sufficient and stable dielectric strength to serve as an insulation between the electrode and the tool.*
- *(vi) The viscosity should also be optimum so that the erosion particles are carried out as soon as produced and good cooling capacity is obtained.*

(vii) It should be free from acid, alkali and corrosion products.

(viii) Properties would no change under different working conditions, varying temperatures, contamination etc.

(ix) It should be easily available at reasonable price.

3.1.5.2 SELECTION OF DIELECTRIC FLUID :

The selection of any dielectric fluid depends on the following parameters:

(i) Size and shape of the work piece.

(ii) Type of material (job) used.

(iii) Tolerance

(iv) Surface finish

(v) Metal removal rate, electrode wear rate etc.

But generally white spirit is use as dielectric fluid. It is best suited for machining tungsten carbide and where intricate details and good surface finish are despaired in small parts. For better finish, the viscosity of dielectric fluid should be less. The dielectric fluid should not be charged frequently on a machine and thus chosen according to the most frequent application.

3.1.5.3 TYPES OF DIELECTRIC FLUIDS

The dielectric fluids generally used are transformer, or silicon oil, white spirit (Kerosene) or paraffin. These dielectric's have the essential dielectric properties, they deionize rapidly and do not vaporize excessively. The dielectric fluid which is used in EDM process are given their description briefly in below:

(i) Hydrocarbon oils
(ii) Water
(iii) Kerosene
(iv) Silicone oil
(vii) Ethylene glycol solutions
(v) Transformer oil
(vii) Paraffin.

(i) Hydrocarbon oils:

It is most widely used dielectric fluid. viscosity is suitable for cut more smoothly after few minutes, of use or conditioning. Its cost is reasonable. Good surface finish is obtained by using this type to oil.

(ii) Water :

Distilled and de-ionized water is used principally for micro machining and wire cutting machines (EDM).

(iii) Kerosene:

It is good for super finishing but infrequently used. Deodorizing recommend and attention to safety precaution. must be maintained. It is suitable for use with tungsten electrodes.

(iv) Silicone oils: Its less frequently used and is more costly.

(v) Gas :

It is very really used

(vi) Transformer oil :

These and insulating oils must with stand large electrical voltages and hence the dielectric strength (usually 1-in disks, 0.1 in gap, 25000 volts minimum) is important. The steam emulsion number is usually specified in order to assure stability during several year of service. This oil is used as kerosene, cost is also reasonable.

(vii) Paraffin :

This can be added to some micro-crystalline waxes without destroying the flexibility. It is very rarely used.

(viii) Ethylene glycol solutions :

It is also rarely used.

3.1.5.4 DIELECTRIC DISTRIBUTION SYSTEMS:

In EDM machining the most important function of the dielectric fluid is the removal of debris or chips produced. This is accomplished by forcing the dielectric through the are gap, with the chips subsequently removed from the dielectric either in settling tanks or by filtration.

The process does not affect the dielectric fluid, which is continuously reusable. So, the correct circulation of dielectric fluid between the electrode and the work piece in EDM is a important aspect as the efficient machining has direct bearing on the correct layout and adjustment of the distribution system. The eroded particles should be flushed out at the earliest as these reduce the further metal removal rate.

The several methods of introducing dielectric fluid to the arc gap fall into four broad classifications:

1. *Normal flow*
2. *Reverse flow*
3. *Jet flushing*
4. *Immersion flushing.*

3.1.5.4.1 NORMAL FLOW:

In the majority of EDM applications, fluid is introduced, under pressure, through one or more passage in the tool and is forced to flow through the gap between tool and work piece as shown in Fig.7. If the work piece has an opening or through hole in the area to be machined, or it the desired machining. operation does not preclude the prior machining of a through hole or passage in the work piece, it is often a matter of convenience or preference to achieve normal flow by mounting the work piece on a coolant box as shown in Fig.8. Fluid is introduced into the box under pressure, and flows through the hole in the work piece to the arc gap. This arrangement becomes advantages in cases where it is difficult to drill a hole in the tool because of tool length or small cross section area.

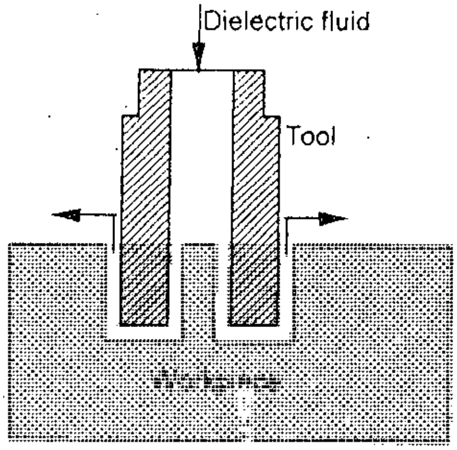


Fig. 7 : In normal flow, dielectric fluid flows through tool and out gap.

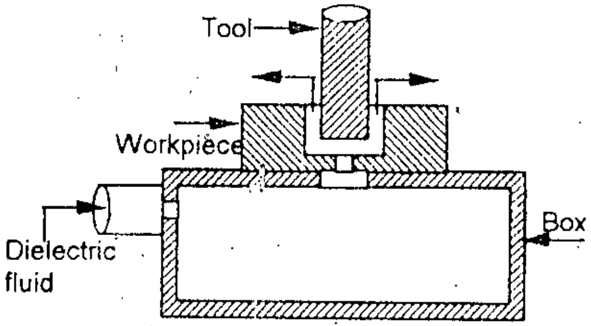


Fig. 8 : Box can be used to introduce dielectric fluid where it is difficult to drill a hole in the tool.

Normal flow is sometimes undesirable because it necessarily produces a tapered opening in the work piece. This is illustrated in Fig.9 which shows an enlarged and dimensionally exaggerated section of an are gap between the tool and work piece, chips produced by machining at the end portion of the tool A must pass through gap portion B. Mere because these chips are electrically conductive they act to shorten the electrical length of the arc gap and enhance sparking. Since all chips produced at A must pass B, the probability of producing side sparking exists.

As the tool advances into the work, with continual flow of chips and side sparking , the gap at area B becomes progressively greater with enlargement of this gap, however the probability that the passing of a single chip will cause side sparking becomes progressively less.

Finally when the side clearance becomes sufficiently enlarged as at C, may chips would have to be aligned to reduce the electrical length of gap sufficiently to permit side sparking. Since the probability of such chip alignment is negligibly low, there is virtually no side sparking at C and no further change in taper.(28)

3.1.5.4.2 REVERSE FLOW :

Taper produced with normal flow can be reduced by properly using reverse flow, with the direction of fluid flow reversed. The gap is submerge in filtered dielectric and instead of applying pressure at the source vacuum is used . With clean fluid flowing between the work piece and tool, there is no side sparking and therefore no taper. With vacuum applied to the coolant box Fig-8, to achieve reverse flow, the quantity of fluid which can be drawn through the arc gap is limited by the relatively low pressure, differential represented by attainable vacuums (10 to 13 psi).

A variation shown in Fig.10 can be used to increase gap fluid flow while retaining the feature of reverse flow. Here an expendable cover or coolant plat is clamped or there wise fastened to the work piece and fluid is introduced into the plate cavity under pressure. First the tool machines on opening C in the coolant plate, and then it advances to cut the work piece. Although there will be some fluid loss through the clearance opening at C. This loss in negligible because of the close fit between the tool and plate, Advantages of this arrangement are the light pressure possible for the reverse flow configuration and the fact that the work piece and tool need not be submerged during the machining process(28).

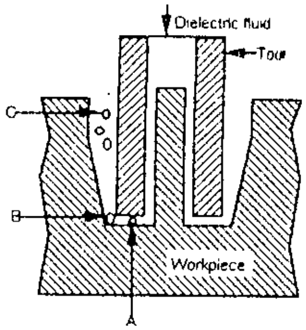


Fig 8 : Normal flow may be undesirable because it produces a tapered opening

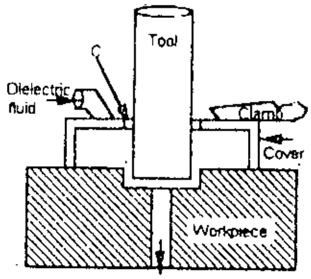


Fig.10 : A variation of reverse flow uded to increase flow of fluid in the gap

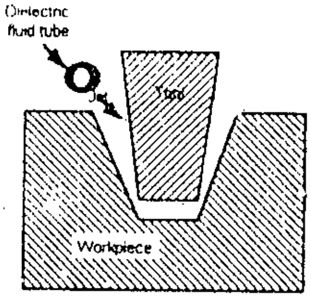


Fig.10a : Tube with seneses of holes or slots can be used to apply jets of fluid into gap

3.1.5.4.3 JET FLUSHING

In many instances, the desired machining objective can be achieved by simply using a spray or jet of fluid directed against the arc gap. The machining of a long narrow slot or cavity in a work piece. As shown in Fig.10 (a) where a tube with either a series of small holes or slots is suitably held in position so that jet of fluid are directed in to the are gap opening. Machining time is almost always longer with Jet flush operation than with normal or reverse flow. However, when tool dimensions are so small as to preclude provision of coolant holes or when the nature of the machining operation does not permit cores or spikes while generally result with holes in the tool , the increased machining time penalty must be accepted$^{(28)}$.

3.1.5.4.4 IMMERSION FLUSHING:

For many shallow cuts or perforation of thin sections, it is not necessary to make provision for fluid flow. Simple immersion of the arc gap in sufficient cooling and chip removal can be enhanced during immersion cutting by providing relative motion of tool and work piece, through periodically vibration or cycle interruption lead also reciprocation of the tool relative to the work piece to effect a pumping action of the dielectric fluid.

3.1.6 Size of electrode:

The size of electrode can be selected properly to account for over cutting and to obtain correct size of cavity over cutting is occur due to variation of size of electrode. It increase with increase in current and decreases at high frequencies.

3.2 SURFACE FINISH (SF) IN EDM PROCESS :

3.2.1 INTRODUCTION :

There is growing need for the manufacture of precision parts in modern industrial environment. The quality of a machined surface is becoming more and more important to satisfy the increasing demands of sophisticated component performance longevity and reliability. The quality of a machined surface is very important for all industrial application such as mold, dies and components used in the aero-spaces, automobile and bio technology industries. Surface finishing of various components is one of the most challenging problems for the industry because of the direct effect the surface roughness has one the functionality and quality of produced parts.

The conventional machining process result in work piece distortions such as burrs, flash and protrusions, therefore most traditional machining process are followed by specify debarring process, to remove the surface defects. Many different processes are used for surfaces edge and corner preparations conditioning and finishing, such as Hand deburring barrel finishing, brushing, buffing and polishing, sand blasting, grinding, honing, supper finishing and lapping. This processes rely on direct mechanical contact between the tool and work pieces and this fundamental physical requirement inherently limits the processes. Conventional methods also induce undesired changes in the work pieces characteristics. Such as residual stresses which required additional processing to be eliminated. More over it is difficult to machine hand materials and complicated shop using conventional machining and finishing techniques. Table-3 shows surface roughness ranges for some process for average application.(22)

Electro discharge machining (EDM) is one of the non-conventional machining processes, which is capable of machining difficult to cut material such as hardened steels, carbides, light strength alloys and electrically conductive ceramics etc. The finished of electrode discharge machined surfaces must be Judged by two criteria.

(a) Surface roughness
(b) Structural change of surface layer.

(a) Surface roughness:

The surface roughness after electrical discharge machining has a different character than that after mechanical machining. The resultant roughness is due to traces after individual electrical discharges which craters mutually over lapping craters on the surface machined.

With an apparently equal roughness of two surfaces machined in different manner the roughness of electrical discharge machined surface has a lower absolute value. The surface roughness depends on :

(i) Tool electrodes
(ii) Dielectric fluid
(iii) The shape of tool electrodes
(iv) Depth of machining and
(v) Kind of work pieces material.

these are discuss in Article 3.1.

(b) Structural change of the surface layer :

The effect of the structural change of the surface layer of an electrical discharge machined material is evident especially with tool steels. This structure has positive effect on the service life of the tool machined which is longer with tools machined by electrical discharge method than with those machined mechanically. The hardness of the affected layer grows with the increasing energy of the discharges.

3.2.2 INDUSTRIAL PRACTICE OF SURFACE ROUGHNESS :

The EDM technology significantly advanced during the late 1980's owing to two major developments ,(1) Improvements to the performance of EDM process & (2) Increased level of automation for EDM.The EDM process has been improved by reduced damage from arcing , lower tool wear ratio and less frequent wire rupture in WEDM. EDM is now a highly flexible technology in terms of machining rate, surface finish and complexity of part geometry. Traditional die sinking EDM units now provide accuracy from ±0.0254 mm to ±0.0127 mm) may drill 50.8 mm deep holes at 30:1 aspect ratios, and remove material as much as 245.8 cm^3/hr Table-4 compare the surface finish of electro dishrag machined components during 80's and 90's (22)

Just 25 years ago the WEDM systems were limited to cutting at only about one Sq. in per hour (6.45 cm^3/hr) without tapering capabilities. Practical maximum cutting speeds in full cut have risen from 1 to 27 Sq. in per hour (174.2 cm^3/hr. Accuracy's have improved from 0.0254 mm to 0.00254 mm) Surface finishes began at 0.7μm Ra and are now 0.3μm Ra(22) . Table-5 compares present capabilities of WEDM systems to that of 1970's WEDM systems in terms of automation, controls, wire types, table travel, accuracy, surface roughness fixtures, maximum cutting speeds and programming capabilities(22). Table-6 shows surface finish currently claimed by 9 major EDM machine tool companies. Fig-11 Shows improvement in surface finish of EDM components since 1970(22).

TABLE-3 : Surface Roughness for some finishing Process

Process	Surface Roughness obtained Ra (μ m)
Barrel finishing	0.8-0.2
Roller burnishing	0.4-0.2
Grinding	1.6-0.1
Honing	0.8-0.1
Polishing	0.4-0.1
Lapping	0.4-0.05
Supper finishing	0.2-0.025

TABLE : 4 : Evolution of surface finish with time in EDM

	1980'S Surface Roughness Ra(µm)	1990'S surface Roughness Ra(µm)
Finishing Machining	1.6-3.2	0.3-1.0
Rough Machining	6.3-12.5	1.25-3.0

TABLE 5 : Developments in WEDM machine

Description	**1970'S**	**1990'S**
1. Maximum height	2 in (50.8 mm)	40 in (1016 mm)
2. Table travel	6x6 in (1524 x 1524 cm)	32 x 40 in (81.28 x 101.6 mm)
3. Control	NC	CNC
4. Automation	Nil	Robotics, Palletizing etc.
5. Maximum programmable tapering angle	0 deg	45 deg
6. Fixture	Toe clamps	Pre staging methods
7. Programming	Manual	CAD/CAM
8. Wire type	Plain Brass	Complex composites

TABLE-6

EDM Surface Finish claimed by some companies :

	Company	**Best surface finish**
1.	Mitsubishi	0.5 µm Rmax
2.	Charmilles	0.127 µm
3.	Hansvedt	0.3 µm
4.	Hitachi	1-2 µm Rmax
5.	Leblond Makino	1 µm Rmax
6.	Japax	<1 µm Rmax
7.	Raycon	3 µm Rmax
8.	Pratt and whitney/ Fanuc	0.0635 µm Rmax
9.	Agie	Ra 0.4 µm

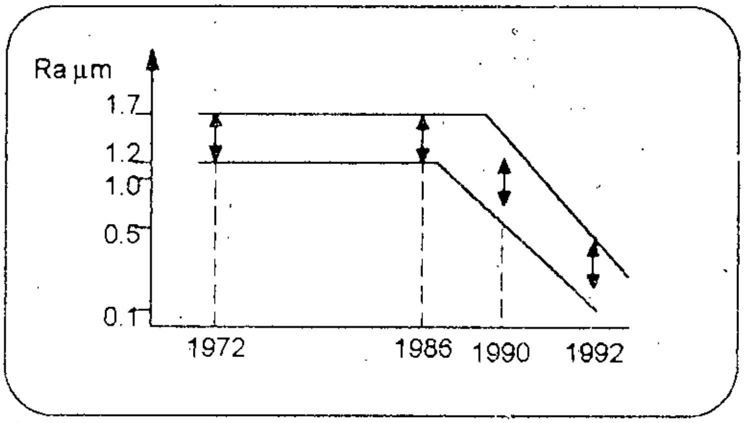


Fig -11 Evolution of obtained surface finish versus time

With the improvement in EDM technology, the use and popularity of EDM for mirror surface finishing and high accuracy machining of complicated parts and hard materials has also increased.

3.3 MACHINING ACCURACY (MAC) IN EDM PROCESS :

3.3.1 INTRODUCTION :

Machining accuracy is the most important technological characteristic of the EDM process. because it determines the applicability of the machine tool for a certain time of production. The accuracy of EDM method is affected by the following factors.

(a) Factors of the electrical discharge method, size of side gap, taper ratio, tool electrodes wear, setting of electrical parameters.

(b) Factors of the production process, accuracy of kinematics machine elements. Production of tool electrode, thermal expansively of tool electrode, adjustment of electrodes.

In the EDM process there are no mechanical forces in the area being machined. It is a contact less machining method. The discharges are created between the tool electrode and the work piece, which remove material form the work piece. To enable penetration of the tool electrode into the work piece, it is necessary to take of the material removed from the inter electrode space. this is done through a gap created around entire circumference between the work piece and the tool electrode. This gap size in determined by the electrical parameter of the discharge and the dielectric properties of working fluid.

The size of the side gap depends on

(i) The selected operating condition.
(ii) The amount of corrosion products passing through it
(iii) The kind and polarity of dielectric fluid and its temperature.
(iv) Operating voltage.

Since with electrical discharge machining the tool electrode is also worn out. it is not possible to machined a give cavity by a single electrode necessity of several electrodes (2 or 3 or 4).

3.3.2 CALCULATION OF TAPER EFFECT AND OVER SIZE :

The size of the side gap is substantially influenced by the technological aperture through which a part of the erosion products passes as a result of which the side gap does not widen. In these case double side gap on the operating conditions when measuring technological aperture. The side gap in not the same on the inlet and outlet side being larger on the former. This means that the hole machined is conical. The conical shape is caused by side discharges and by the wear of the tool electrode. However, this conical shape is advantages when making trimming dies. The purity of dielectric fluid and its temperature influence the size of the side gap in such a manner that with increased pollution the size of the gap also increases this is caused by the tool that particles of the metal continued in the fluid move in to gap facilitating side discharges as a result the gap widens.

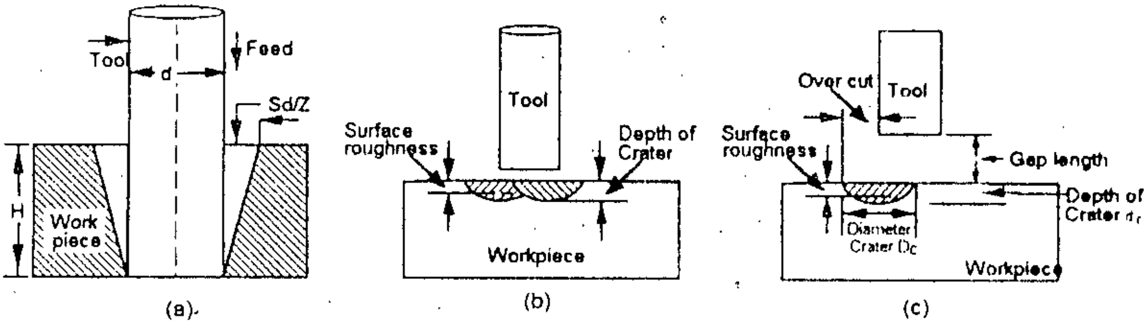


Fig.12 : Taper effect and over size product on the machined surface

If d = diameter of tool, then maximum variation in radius of the hole at distance H from bottom of hole or on top surface of word is $\delta d /2= k.(\Pi/4).d^2 .H$ Fig-12(a). Where

k = constant and thus tapper effect = $(\delta d/2)/H$.

Further in EDM process, over cuts are produced in the work pieces because of the presence of side sparks. The over cuts depends on the gap length and crater size. An over cut of 5-100 μm in produced depending upon the finishing or roughing operations. corner radii equal to the spark gap are also produced. Fig 12(c).

The surface produced by this process consists of micros-copies craters and the quantity of the machined surface mainly depends on the energy per pulse. If the energy content per pulse in high then the depth of crater will increases causing a poor surface finish and vice versa .Fig 12(b).

3.3.3 HEAT AFFECTED ZONE :

Directly beneath the hard skin is a heat affect zone , which in the case of heat treated materials is softer than the parent metals. The melted material in not completely removed by part of it re solidifies on the machined surface to form a hard skin about 2-10μm deep. Thermal stress, plastic deformation and fine cracks form in this grain boundary. So, that in the EDM process accuracy of the work piece in the important. In this project work the related obtainable accuracy characteristics are also presented. The characteristics of the EDM process shown in the Table -7

TABLE- 7 : CHARACTERISTICS OF EDM PROCESS :

Mechanism of process	Controlled erosion (melting & evaporation) through a series of electric sparks
Spark gap	0.010-0.125 mm
Spark frequency	200-500 KHZ
Peak voltage across the gap	30-250V
Material removal rate (max.)	5000 mm/min
Specific power consumption	2-10w/mm/min
Dielectric fluid	Kerosene, Liquid praffin, silicon oil
Tool materials	Brass, Copper, Graphite, Ag-W alloys, Cu-W alloys
Tool wear rate	0.1-10 mm^3/ min
Material that can be machined	All conducting metals and alloys
Shapes	Any types
Limitations	High specific energy consumption and non conducting material can not be machined.

CHAPTER FOUR

EQUIPMENT AND EXPERIMENTAL PROCEDURE

4.1 Components of the Experimental set up :

The following equipment were used for the determination of appropriate tool material at a given condition in EDM process :

1. *Dial indicator*
2. *Microscope*
3. *Surface roughness measuring equipment*

Dial indicator :

This is the simplest form of deflection measuring device and can measure accurately up to 0.0005″ when functioning properly. These will be rigidly mounted with the suitable stand. A lever system is frequently used in conjunction with a dial indicator. So that by this instrument the depth of cavity of machining surface can be easily measured.

Microscope:

An instrument microscope was used to measure the actual wear of the tool electrodes. Both thickness of recast layer and micro-structure were measured by this instrument. Wear and recast layer thickness can also be measured easily .

Surface roughness measuring equipment :

The surftest AB-5 is a stylus type of surface roughness measuring instrument used to take to have accurate measurement of surface texture at high magnification. The quantity of the irregularity concerning surface texture can be represented as deviation from the nominal surface in terms of roughness, waviness and straightens. The mechanical displacement of the stylus given while traveling measured surface is cornered into electric quantity through strain gauge of bride circuit to be amplified in the amplifier recording unit to a desired vertical magnification. The horizontal magnification is determined by the stulus spaced and chart feed speed. Shachtamatic diag. is shown in Fig 14 .

4.2 DETAILS OF WORK PIECES AND ELECTEODES

The experiment were carried out in the laboratory of BUET. The work material were brass, copper, mild-steel, stainless-steel and cast-iron, which were purchased from local market. The electrodes were also of the same materials . The work piece size was 13 x 13 x 3 cm. It was ground on a surface grinding machine and Five cylindrical electrode were fabricated from brass, copper, stainless-steel, mild-steel, and cast-iron by turning in lathe machine. Electrode dia was 11mm. The shape of tool holder was cylindrical.

4.3 CONDITIONS AND ASSUMPTION OF THE EXPERIMENT :

From the earlier theoretical investigation it was observed that tool wear ratio, material removal rate and surface roughness depends on conductivity, melting point polarity gap between electrode and work piece etc. Influence of the

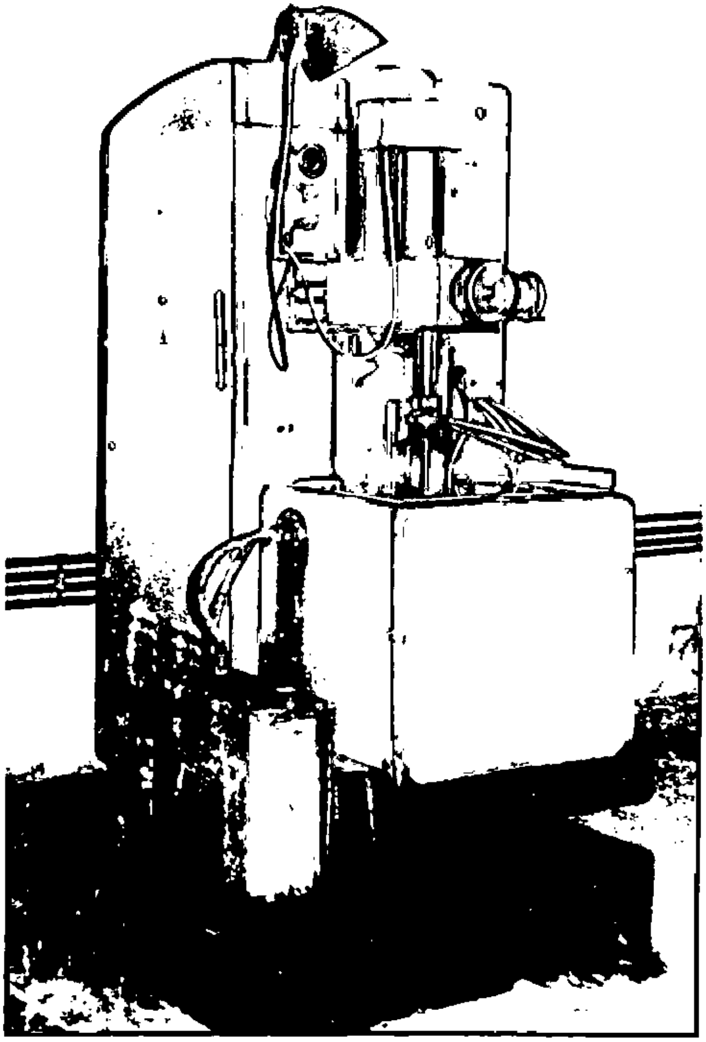


Fig - 13 Experimental equipment set up

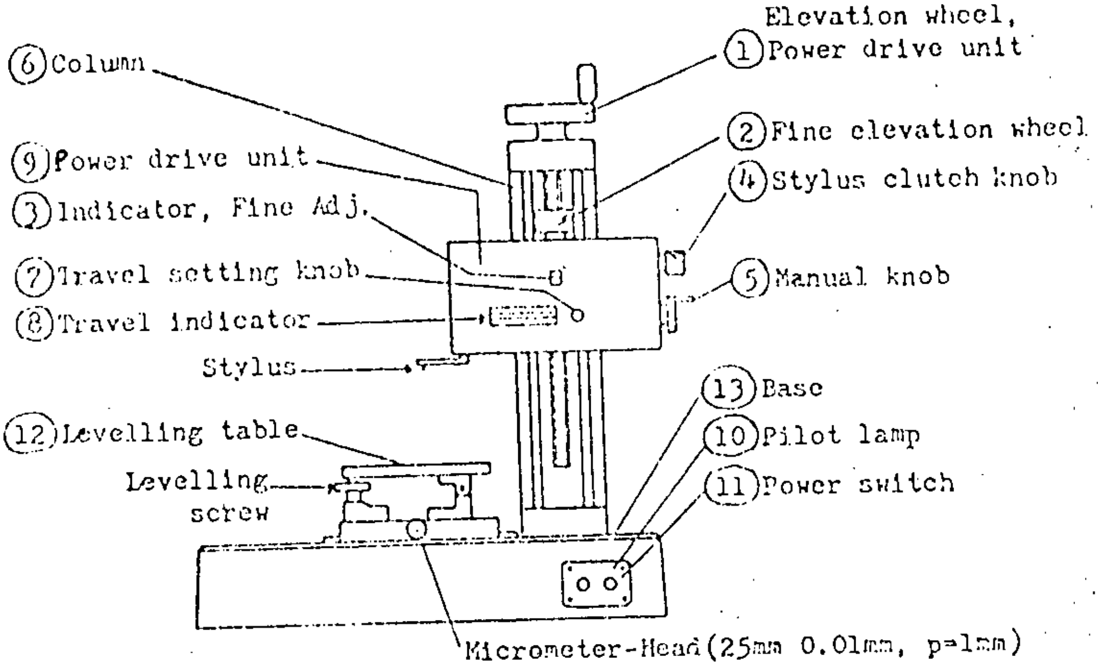


Fig - 14 Surface roughness measuring instrument magnetic properties on the tool wear was neglected through out of the investigations. Although dielectric fluid influence material removal rate yet only immersion flow type fluid flow was used. In this experiment current also maintain constant through out the whole study.

Following assumption were made during the study :

(a) Temperature and Pressure of dielectric fluid were assumed to be constant.

(b) Formation of recast layer on the machining surface occurs at steadily state condition.

(c) The properties of recast-layer differ from parent material.

(d) Machining conditions and voltage were constant.

(e) Particles were eroded uniformly from the electrode

(f) Constant flow of dielectric fluid was maintained through out the investigation.

4.4 DETERMINATION OF MATERIAL REMOVAL RATE, WEAR RATIO AND SURFACE ROUGHNESS :

Experiments were conducted on an electrical discharge machine employing pulse generator and electro mechanical type servo motor for gap control (Manufactured by chechoslovakia, Model No.-18401). Brass, copper, mild steel, stainless steel, cast iron tool and work piece materials were machined and ground to the size. To reduce the data taking time, one hole for each electrode was performed on the job material . Thus 25 holes were formed for five electrodes on the five types of job materials. Machining was performed at right angles to the job surface. The dielectric fluid (Kerosene) was supplied from the main tank filters to the working place tank.

The tool electrodes were held mechanically on the tool holder and machining the work piece at a fixed time. Depth of cavity was measured by using a dial indicator and the tool electrode wear was measured using microscope after a fixed interval of machining.

The following parameters were calculated

(i) Material removal rate (MRR)
(ii) Wear ratio (WR)
(iii) Surface roughness (SR)

MRR was based on the measurement of volume loss of work material per minute of machining time. All the MRR were carefully calculated using the following. equation.

$V = (\Pi /4).d^2 l \ (mm^3/min)$

Where V = Volume of material in cu.mm
d = dia of hole in mm.
l = depth of hole in mm.

The wear ratio (WR) of the electrode is defined as the percentage of volume of electrode wear per unit volume of material removal in the same machining interval. Table 14-23 shows the MRR and Table-9 shows the WR for different combination of electrode and job materials. The average surface roughness Ra was measured on sulftest AB-5 using styles tip size and cut of length 0.5 mm at velocity 250 m/min. Table-8 shows the roughness for different combinations of tools and work materials.

TABLE-8 : AVERAGE SURFACE ROUGHNESS VALUE (μm)

TOOL MATERIALS	JOB MATERIALS				
	Brass	Copper	Stainless steel	Mild steel	Cast iron
Brass	15.43	11.06	15.44	14.00	19.56
Copper	16.50	12.67	19.55	20.23	21.50
Stainless steel	17.23	18.45	23.80	27.50	25.10
Mild steel	23.64	19.00	30.27	37.18	30.12
Cast iron	30.27	20.10	31.95	40.80	35.13

TABLE - 9 : TOOL WEAR PER UNIT OF JOB MATERIAL REMOVAL

JOB MATERIALS	TOOL MATERIALS				
	Brass	Copper	Stainless steel	Mild steel	Cast iron
Brass	0.321	0.716	0.925	0.817	0.893
Copper	0.103	0.419	0.400	0.438	0.552
Stainless steel	0.121	0.438	0.470	0.485	0.559
Mild steel	0.129	0.465	0.550	0.530	0.659
Cast iron	0.112	0.445	0.670	0.470	0.590

4.5 DETERMINATION OF MICRO SIZE CAVITY AND RECAST LAYER

To take the micro size cavity and photograph of each specimen the machined specimen were sectioned in the middle at right angle by using hacksaw. One part of each specimen was then mounted and polished by standard metallographic techniques then these specimen were examined by optical microscope (x 1000) and measured the thickness of recast layer and take photograph of micro-size cavity and recast layer of different specimen. The thickness of Recast layer were shown in Table-10.

TABLE : 10 : THICKNESS OF RECAST LAYER (μm)

TOOL MATERIALS	JOB MATERIALS				
	Copper	Brass	Mild steel	Stainless steel	Cast iron
Copper	2.60	2.50	1.20	2.50	1.00
Brass	2.20	2.10	1.00	2.25	0.95
Stainless steel	2.00	2.10	0.91	2.10	0.80
Mild steel	1.80	1.90	0.85	2.00	0.70
Cast iron	1.72	1.70	0.70	1.15	0.65

TABLE: 11 : EXPERIMENTAL EQUIPMENT'S:

EDM power source	Input 13.5 VA open circuit voltage of power supply approximately 490V and voltage on electrode approximately 230-250V .Feed regulation with two phase regulating servo motor controlled by magnetic amplifier
Electrodes	Copper, Brass, Stainless, Mild steel, and Cast iron (11mm. in dia)
Work material	Same as electrode
Working fluid	Kerosene
Measuring device	Dial indicator, Microscope, surface roughness measuring equipment

TABLE- 12 : CONDITIONS OF EDM :

Feed rate	(f)	0 ~ 1 mm/min. (servo- control)
Gap voltage	(v)	2-3V
Peak current	(I)	0.4 ~ 0.5A
Machining time	(t)	225 mins.

CHAPTER FIVE

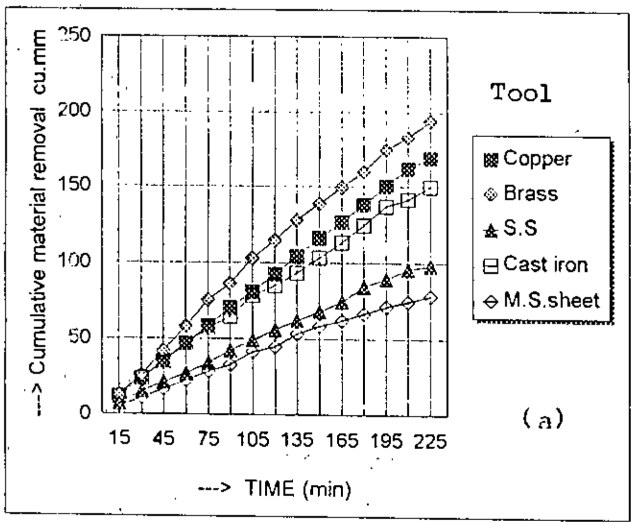
RESULT AND DISCUSSION

5.1 GENERAL

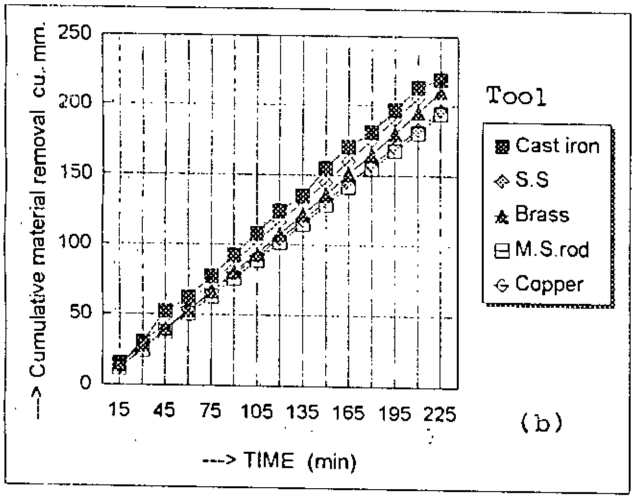
The test programme was performed in a systematic way and the necessary test data are presented in the preceding chapter. These data were recorded during the testing operations as accurately as possible. These test data are analysed and discussed in the following articles.

5.2 MATERIAL REMOVAL RATE (MRR)

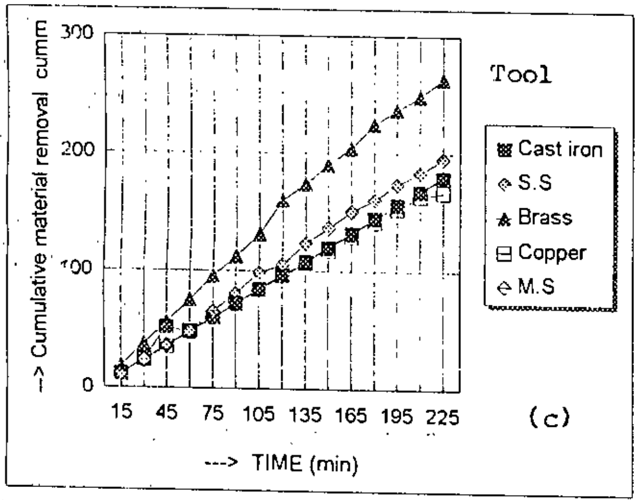
Curves of MRR versus machining time were plotted using Lotus 1-2-3. it is observed from these relationship that in different cases MRR are different. It is also observed that MRR increases with the increase in discharge duration (Table 14-23). This occurs due to the fact that pulse energy increases with time. MRR does not show linearity in all cases. It shows convex behaviour with time (Fig-15). Due to the possible losses of thermal energy by conducting to surrounding material and dielectric fluid. An increase in discharge duration beyond certain limit, for a given electrode and job material has adverse effect on MRR and electrode wear. More over this leads to arcing for carbon deposition on the both the machining surface and the electrode. Apart from that the particles which come out after erosion do not get effective expulsion due to lack of turbulence of the dielectric fluid. Therefore the particles remaining on the machining surface interfere with the discharge process and resist the pace of erosion. This is the another cause of reduction of



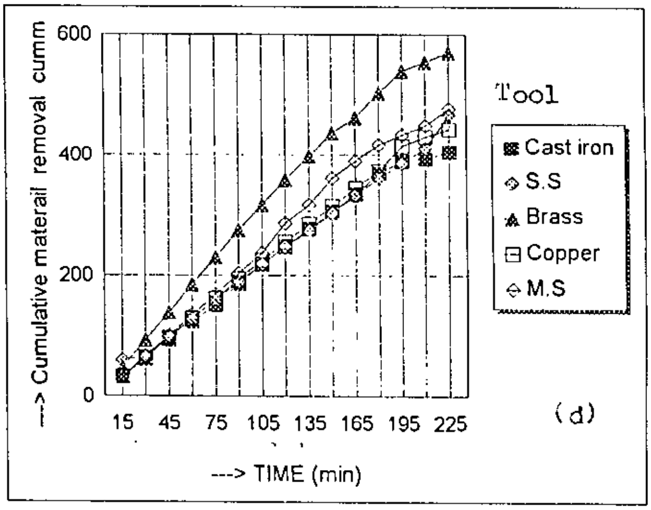
(a) Job material : Mild steel



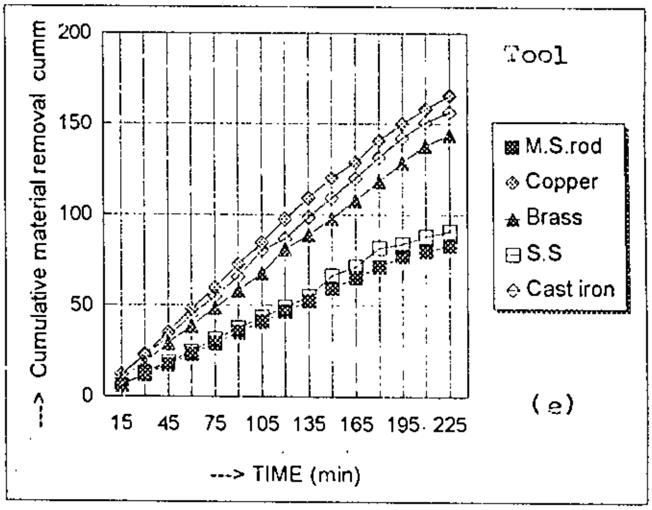
(b) Job material : Cast iron



(c) Job material : Copper



(d) Job material : Brass



(e) Job material : Stainless steel

Fig - 15 Cumulative material removal from different job material machined by different electrodes in finish cut

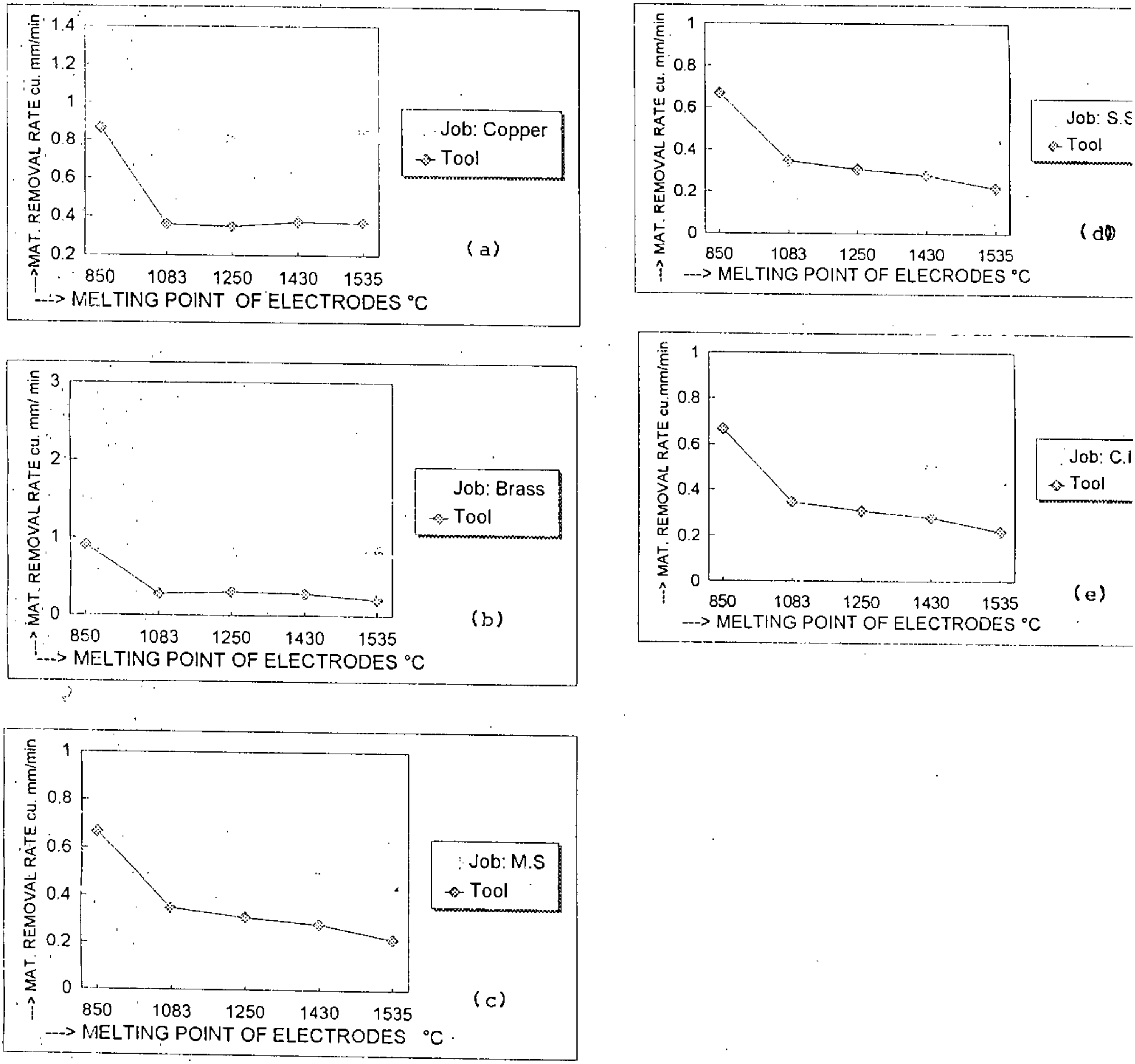


Fig - 16 Tool wear rate of different tool versus melting point of tool materials

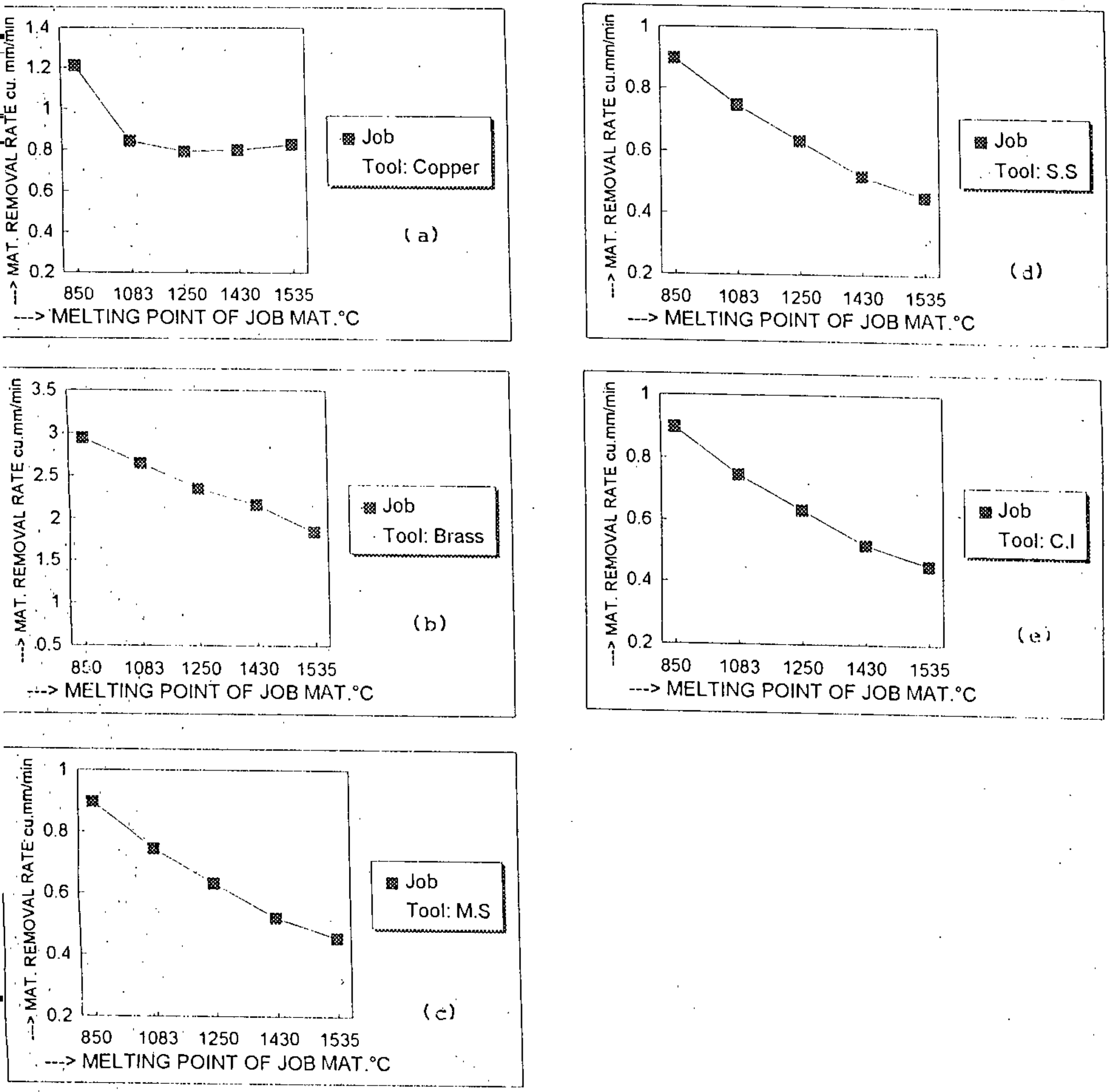


Fig - 17 Material removal rate of different job materials versus melting point of job materials

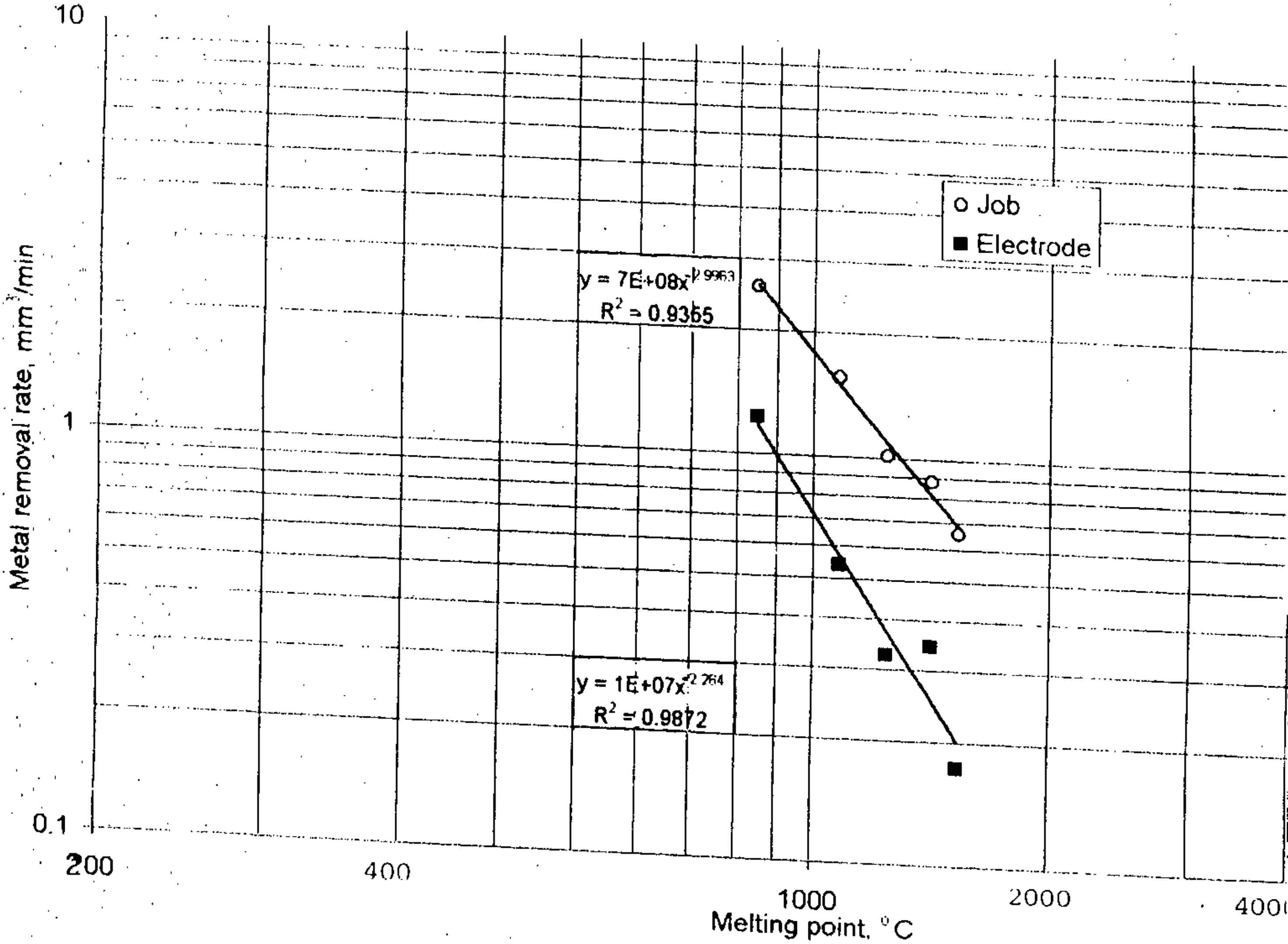


Figure 18. Average metal removal rate versus melting point

MRR. At low discharge duration, the MRR for different job material are approximately the same (Table 14-23). In this case the thermal energy do not penetrate deeply into the job material. As a result shallow craters are produced. This phenomenon leads to low MRR.

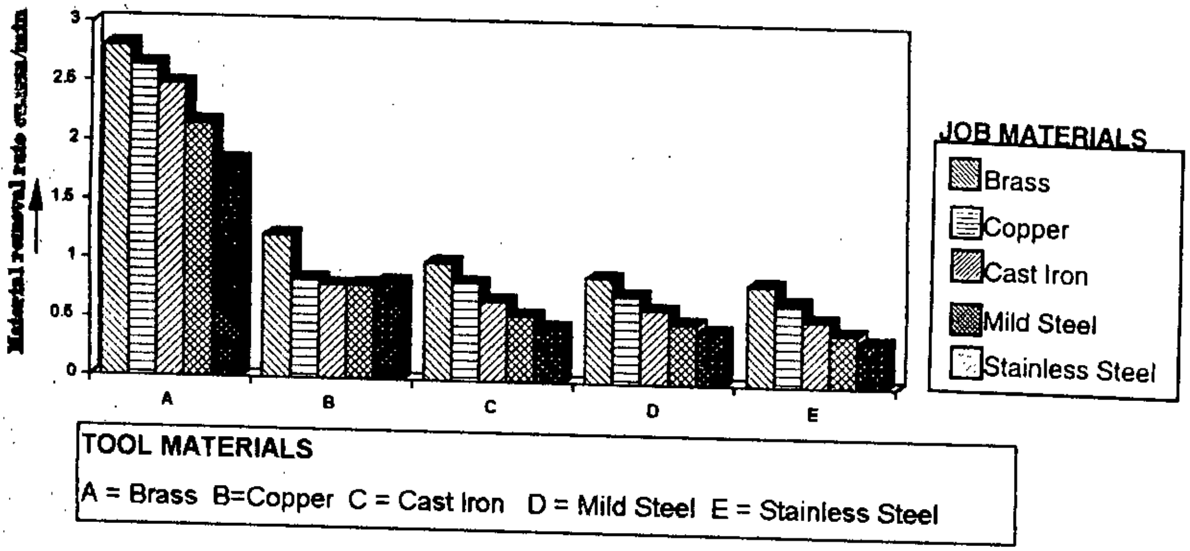


Fig. 19 : Material removal rate for different job material machined by different electrodes.

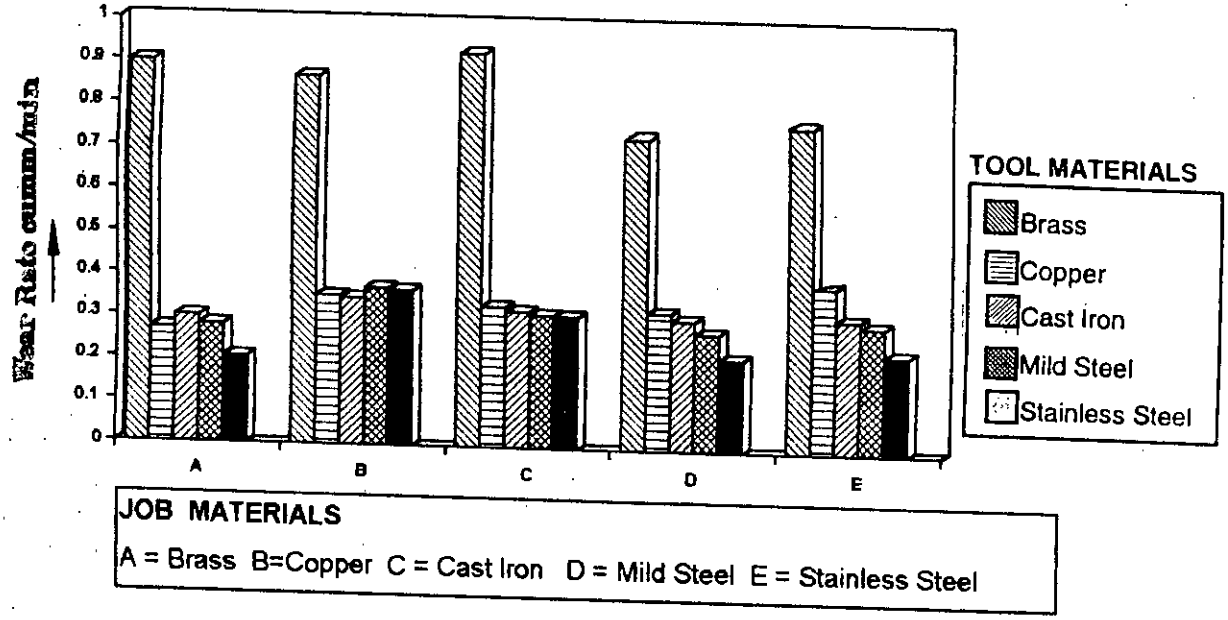


Fig. 20 : Tool wear rate for different electrodes used on the different job materials.

Fig 16 show the relationship between wear of different electrodes versus melting point of those electrodes. It is observed that low melting point electrodes are removed at higher rate than the higher melting point electrodes. It also shows that if melting point of the job material increases the MRR occurs at decreasing rate in different combinations. In this case the wear rate of tool is approximately the same. But there is no linear behaviour in these cases.

Fig -17 show the relationship between material removal rate of different job materials and melting point of job materials.It is observed that low melting point job materials are removed at higher rate than the higher melting point materials. There is linear behaviour in the case of job materials removal.

Curves of MRR versus melting points of job and electrodes are plotted using microsoft windows version 6.0 on log- log scale (Fig 18). It is observed from the figure that MRR of the job materials are higher than the wear rate of electrodes, this is because of the fact that during discharge period electrons move from the cathode (tool) towards the anode (work piece) causing bombardment of the anode particles. Since the bombardment is caused by the electrons its energy is higher. On the other hand the cathode is bombarded later by ions from the decomposed dielectric and also by ions and particles from the vaporised anode. Since the bombardment in this case is caused by ions rather than electrons, the rate of transfer is slower and rate of erosion is consequently lower.

Bar charts of MRR for different job material for different electrode at a fixed time are plotted using lotus 1-2-3 (Fig 19). From these charts it is observed that maximum MRR are occurs in the case of Brass electrode for low melting point job materials. For Copper electrodes MRR is higher in the case of higher melting point materials.

Fig.20 shows that higher tool wear occurs in the case of Brass electrode. Other electrode shows the different rate of wear ratio, due to their different properties such as melting points, thermal conductivity, polarity and other properties as discussed above. By using Fig 15-20 find out the proper tool material for maximum material removal rate and low tool wear material for different applications.

5.3 WEAR RATIO (WR)

The wear ratio of the electrode is defined as the percentage of volume of electrode wear pert unit volume of material removal in the some machining interval. The WR of different tool material are shown in Table-9. It is observed that in all cases minimum wear ratio is achieved in the case of copper electrode and maximum wear is observed in the case of brass electrode. The copper electrode shows low wear ratio (WR), due to high conductivity of heat than other electrodes. As a result of higher resistivity of the job material than that of copper tool, more heat is generated on the work piece and the relative wear ratio is always less than one. The brass electrode shows the higher wear ratio (WR) for its lower melting point. As a result its particles are eroded at a low temperature, which leads to higher wear ratio (WR) than other electrodes. Table-9 also show that in case of the mild-steel and stainless-steel as a job material, the wear ratio (WR) is higher. So for hard materials Brass is not suitable as an electrode material. Wear ratio for different tool electrodes are represented by bar charts (Fig 21).

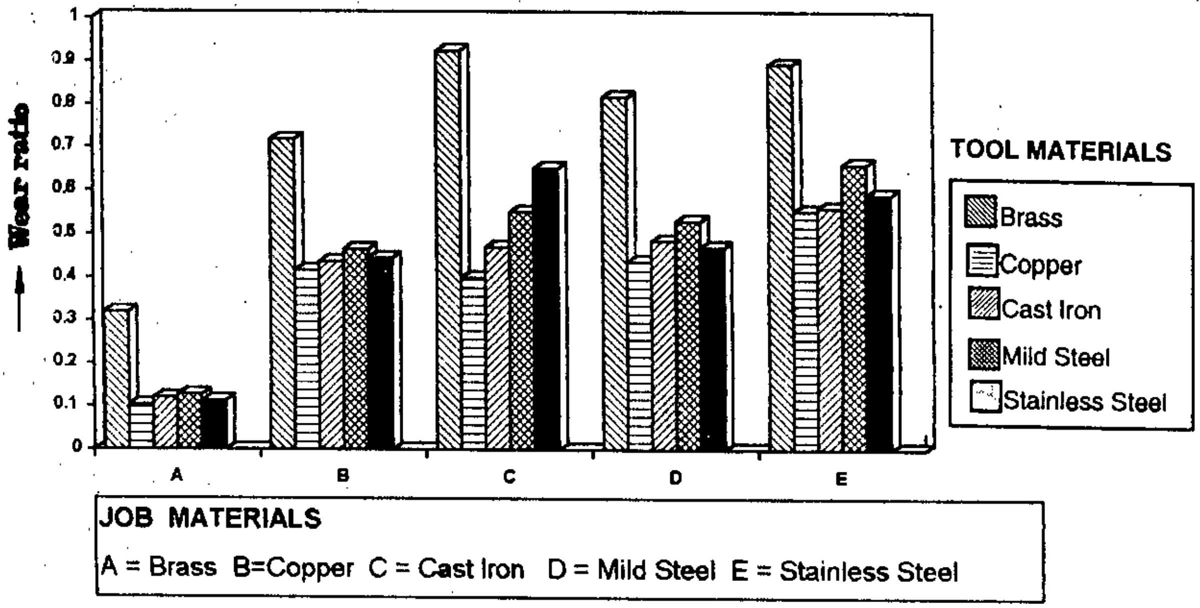
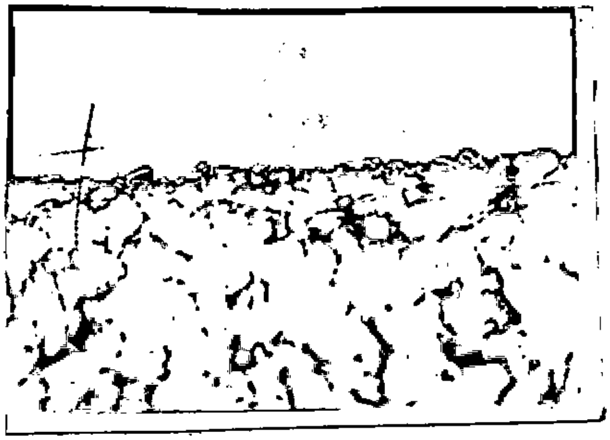


Fig. 21 : Tool wear per unit of job material removal

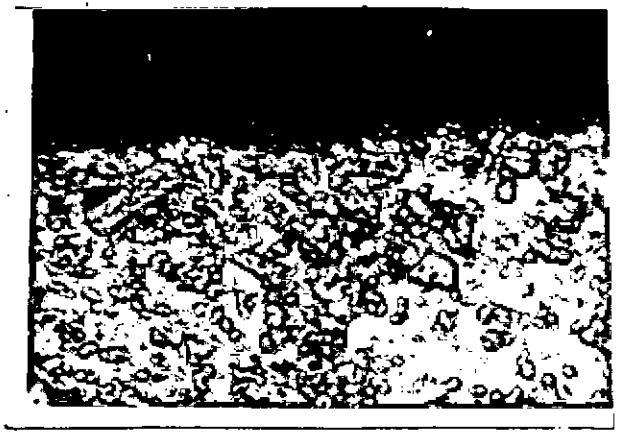
5.4 RECAST LAYER (RCL)

The machined specimens were sectioned in the middle, polished and etched. Optical microscope photographs of the recast layer are shown in Fig. 22, and thickness of the recast layer on the machined surface are represented by bar charts (Fig. 24). The recast layer thickness for different job material is different due to variation of thermal conductivity of material. This layer is also termed as the white layer due to its appearance. It is unetcheable and can be easily identified (Fig. 23).

Tool : Cast iron Job : Brass

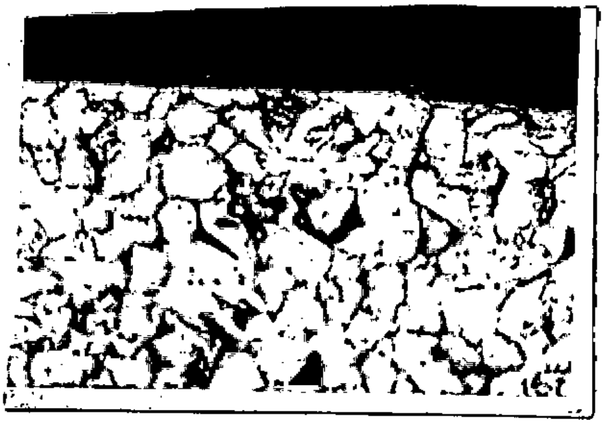


Tool : Brass Job : Mild steel

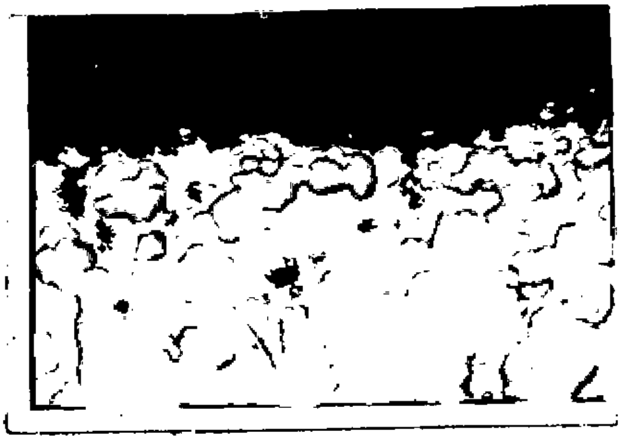


Tool : Copper Job : Mild steel

Tool :Mild steel Job : Mild steel



Tool : Cast iron Job : Mild steel

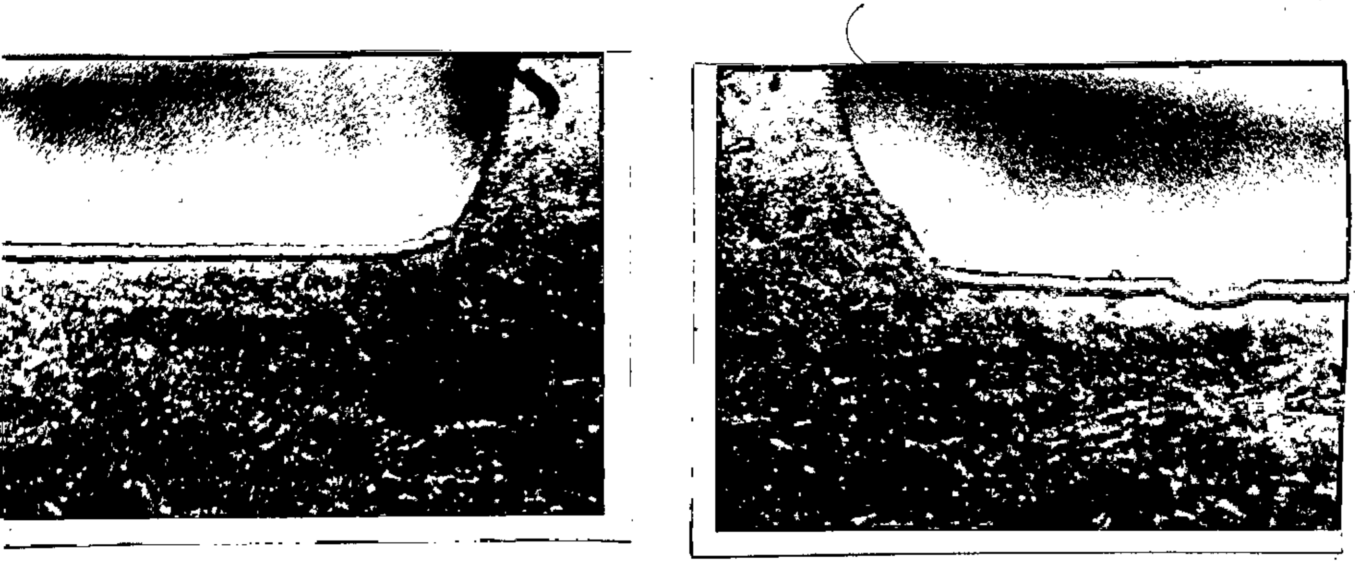


Tool : Stainless steel Job : Brass

Fig - 22 The recast layer on different surface machined by different electrodes (x 600)

Tool : Brass Job : Brass

Tool : Copper Job : Brass



Tool :Mild steel Job : Stainless steel

Tool :Cast iron Job : Stainless steel

Tool : Stainless steel Job : Mild steel

Fig - 23 The recast layer on different surface machined by different electrodes with out etching (x 400)

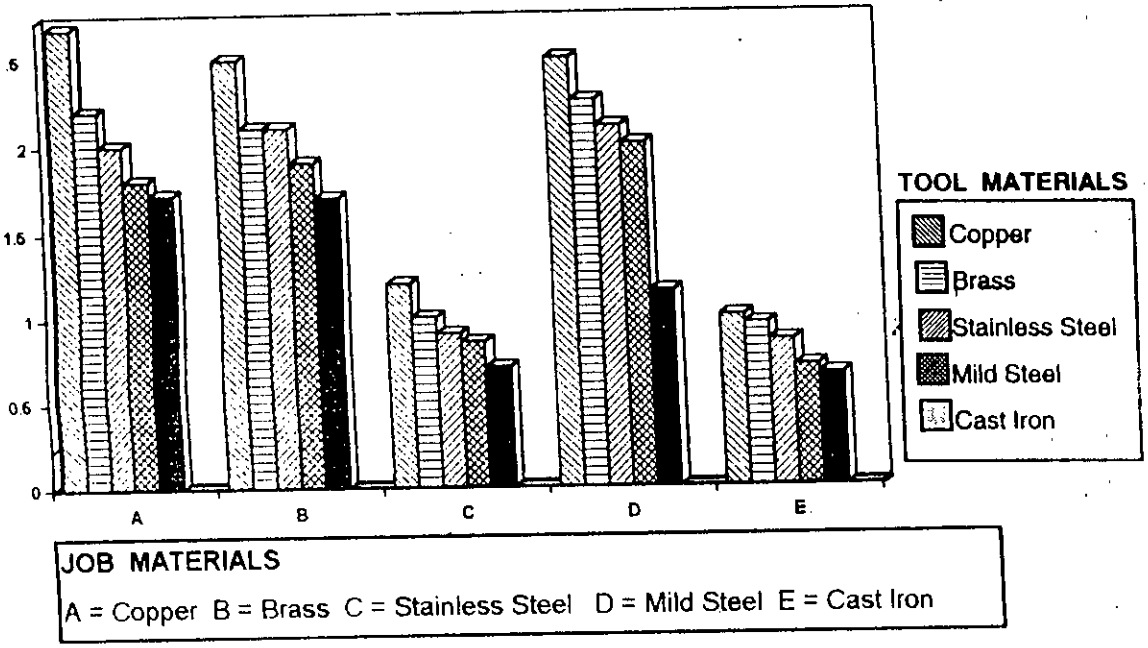


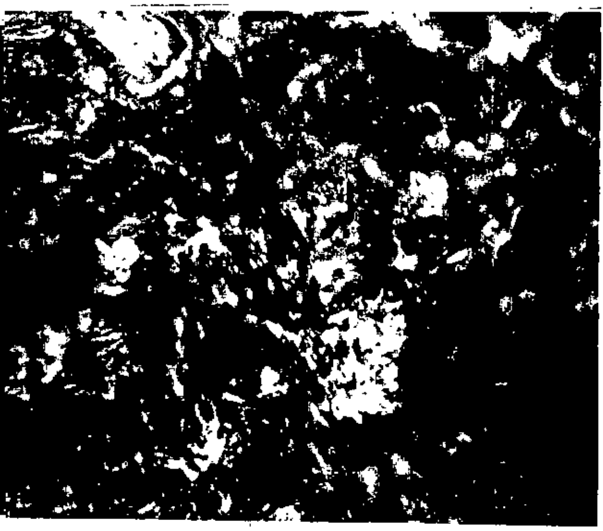
Fig. 24 : Thickness of recast layer of different job material machined by different electrodes

The repetitive sparks release energy in the form of local heat. As a result of this local temperature reach a higher value at the spot of electrical discharge. At such some metal particles are melted and eroded. Some of them vaporized and some are flushed away by dielectric medium (liquid). Some droplets of the particles trap the loosened particles and gas and then solidify on to the previously eroded surface to form a RCL. Thermal stress, plastic deformation & fine cracks form in the grain boundary. This layer is chromatically different from the original surface when observed with polarized light and viewed under a microscope.

Since the electrode penetrates vertically from the top of the specimen, it prevents the dielectric from effective flushing of the particles at the bottom of an EDM hole. As a result these particles are deposited on to the surface increasing the reinforcement of the RCL.

Cast Tool: Copper

Job: Stainless steel Tool:Copper



b: Brass Tool: Copper

Job: Copper Tool: Brass

: Mild steel Tool: Stainless

Job: Brass Tool: Mild steel

g -25 Different electrical discharge machining surface (x 800)

Fig. 24 show that in all cases the copper electrodes form a RCL, of higher thickness than other electrodes due to the fact that the particles which are eroded from copper electrode having higher density of heat are able to penetrated a higher thickness of job materials. Fig 25 also shows that there is no irregular shape of the RCL is formed on the machining surface in the case of conductive materials (copper, brass). In the case of brass electrode a similar type of homogeneous RCL is also formed but its thickness is lower.

Sometimes irregular RCL and cracks are formed probably due to uneven heating and cooling of the particles in the dielectric fluid and low conductivity of heat of the job material. As a result poor surface finish is attained. This occurs specially the case of cast iron.

Since the temperature of the particles adjacent to the dielectric fluid falls below freezing point and many solid nuclei are form which grow rapidly to form new grain, so large number of nuclei equiaxed fine grained structure are formed quickly. These are formed when copper and brass electrodes are used. Higher thermal conductivity is the another cause of formation of such type of structure.

In the case of stainless steel, mild steel, cast iron, due to their low conductivity of heat form columnar grains. Columnar growth continues until opposite sets of columnar crystal are met. If nucleation occurs in the Centre then coarse equiaxed crystals will be formed.

Fig 22 also shows that fine grained structural surface is formed by copper & brass electrode on the machining surface. Any molten metal which is not expelled during the process is re-solidified to form a hard skin on the surface.

Thermal stress, plastic deformation and shrinkage result in residual tensile stresses and fine cracks above the grain boundaries. Directly beneath the hard skin is a heat affected zone, which is the case of heat treated materials. This layer is softer than the parent metal. Since copper electrode form RCL of higher thickness, this leads to a harder skin in form on the surface longer life of the product. Lower friction and lubricant retaining properties as is desirable for dies, so for machining dies copper electrode is best suitable.

5.5 HEAT AFFECTED ZONE (HAZ) :

In this study the existence of HAZ was induced from the fact that depth of soften zone is always deeper than that of the corresponding RCL. This softened HAZ is below the RCL and is different from it. However it is not visually identifiable in this experiment.

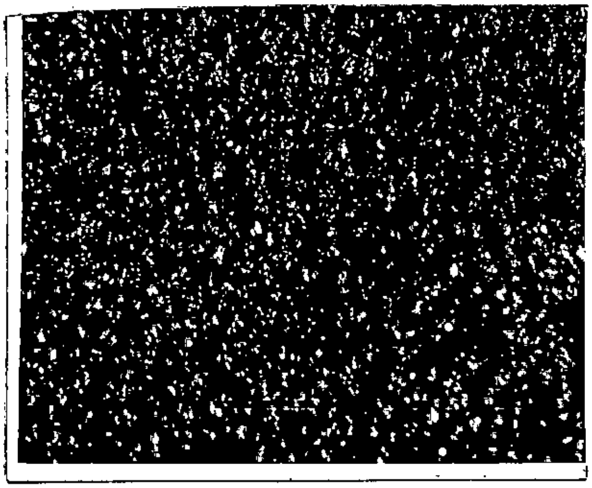
HAZ is formed by Bombarded of ions of opposite sign during on time, a layer of the work piece in melted and evaporated. Driven by a high thermal gradient heat must transfer conductivity to a deeper layer and raise its temperature above the solid solution temperature. This layer rapidly cools down during the off time because of massive volume of the surrounding cool dielectric and become the heat affected zone. This occurs in the case of brass, cast iron and mild steel electrode. But does not occur in the case of copper and stainless steel.

Since copper and Brass electrodes have high conductivity of heat, so heat affected zone will also be of higher thickness, this leads to higher thickness of RCL, is desirable. But other types of electrodes form a HAZ of smaller thickness. As a result RCL is also smaller. So, the machining surface is not hardened and it may be cracked during operation, which is not desirable. So in this point copper electrode is the best electrode.

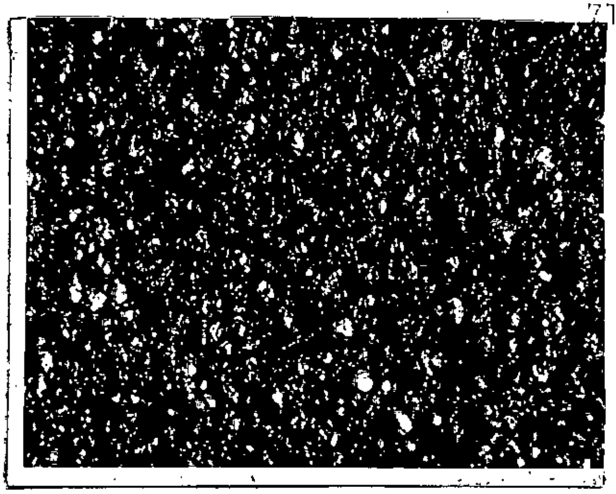
5.6 MICRO SIZE CAVITY :

Micro size cavity, which is formed on the machining surface is shown in Fig. 26. It may observed from the Fig. 26 that the cavity formed by the brass and copper electrodes is small in size. Due to high conductivity of heat than that of formed by other electrodes. The size of the cavity produced on the work piece surfaces by electric sparks depends on the energy of the discharge. The discharge is determined by gap voltage during discharge, the discharge current and the discharge time.

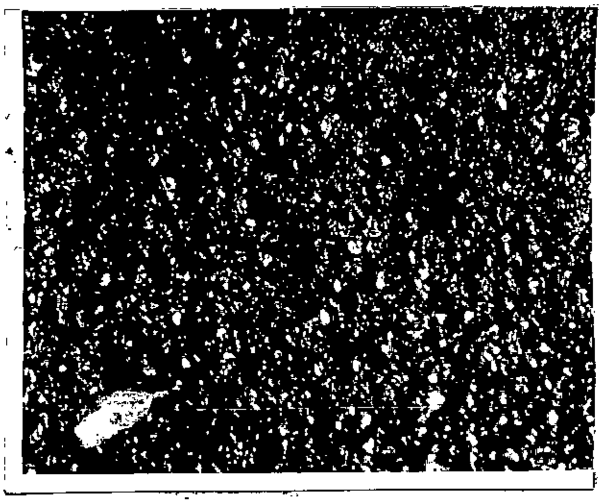
Also higher discharge frequencies and higher discharge energy improved surface finishes. So, by using copper and brass electrode, it is possible to form a fine surface finish for formation of smaller cavity on the machining surfaces. These microscopic solid and hollow sphere are of 3μm to 5μm in diameter. The smaller quantities of liquid metal remaining in contact with crater base then undergo the physico-chemical changes associated with an extremely high cooling rate. But in the case of mild steel, stainless steel and cast iron electrodes which have low thermal conductivity, emit lower density of charge. So these particles can not melt fully the particles of work piece, as a result some of these particles deposits on the machining surface, leading to the formation of microscopic solid and hollow spheres about of 8-20μm in diameter and also form a rough surface profile as discussed in earlier.



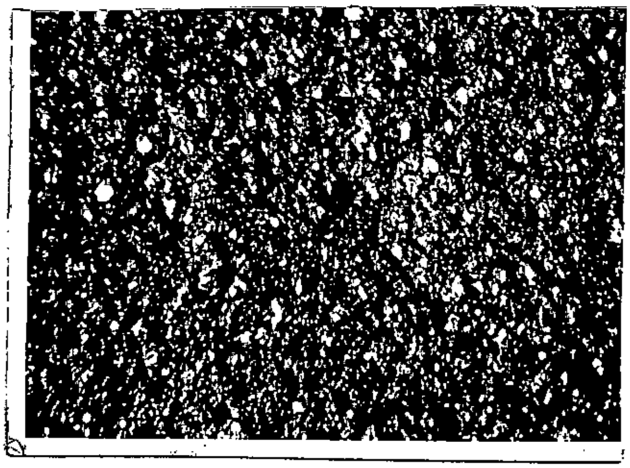
Tool : Brass



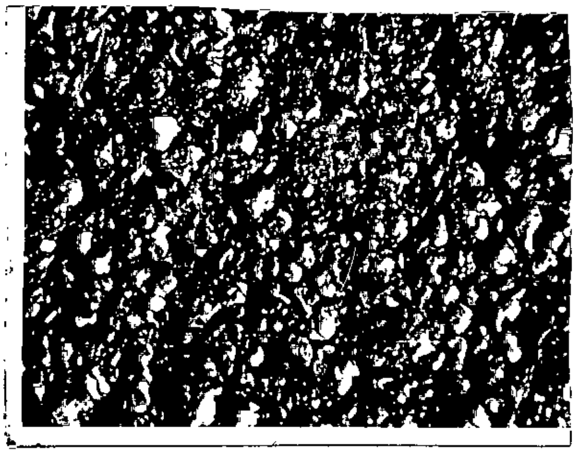
Tool : Copper



Tool : Stainless steel



Tool :Cast iron



Tool : Mild steel

Fig - 26 Micro size cavity produced on Mild steel material machined by different electrodes (x 50)

So from above the discussion it is clear that brass or copper electrodes ensure superior smaller micro size cavity & smaller amount of deposition on the machining surface in the form of recast layer . (Fig. 26b)

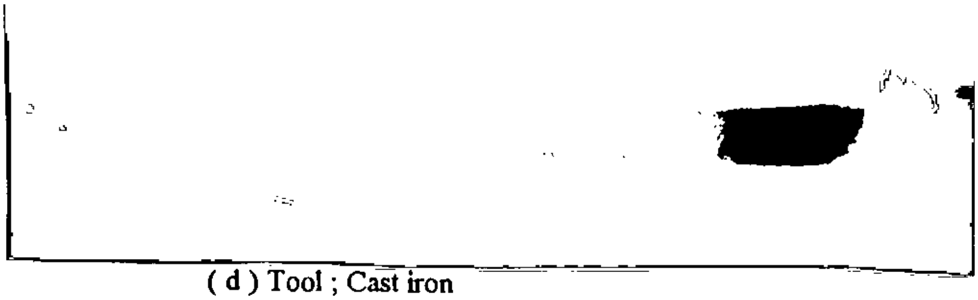
5.7 TOOL WEAR AND ACCURACY OF THE MACHINED SURFACES :

Fig. 27a-27e shows the tool wear and over size of the cavity on the machined surface by different electrodes and 27f shows the schematic representation of tool wear (dark area) and over size . The hole oversize occurs due to higher sparking incidence at the side surface. The debris (chip) concentration also increases for side sparking of tool electrode. Similarly the tendency of debris to concentrate at the middle of the tool work interface result in high bottom surface in accuracy when duration of discharge is increased. Fig. 27c shows that brass electrodes form a convex surface on the machining surface when higher melting point material are machined. Because the particles of electrode near to the dielectric fluid falls below freezing point and becomes too hard, than middle portion, are melted and remove quickly. So the surface of tool form as a concave shape. Since the profile of machining surface depends on the electrodes surface so, in this case machining surface is also convex shape due to tool profile. But when high thermal conductivity material is used as tool electrode there was absence of concavity due to fact that the particles at middle portion also gain freezing point as soon as possible like side particles. In the case of copper electrode, the bottom surface was flatness and side taper was also law, leads to the accurate shape of hole cavity, corner radius is also minimum shown in Fig. 27d.

(a) Tool : Brass

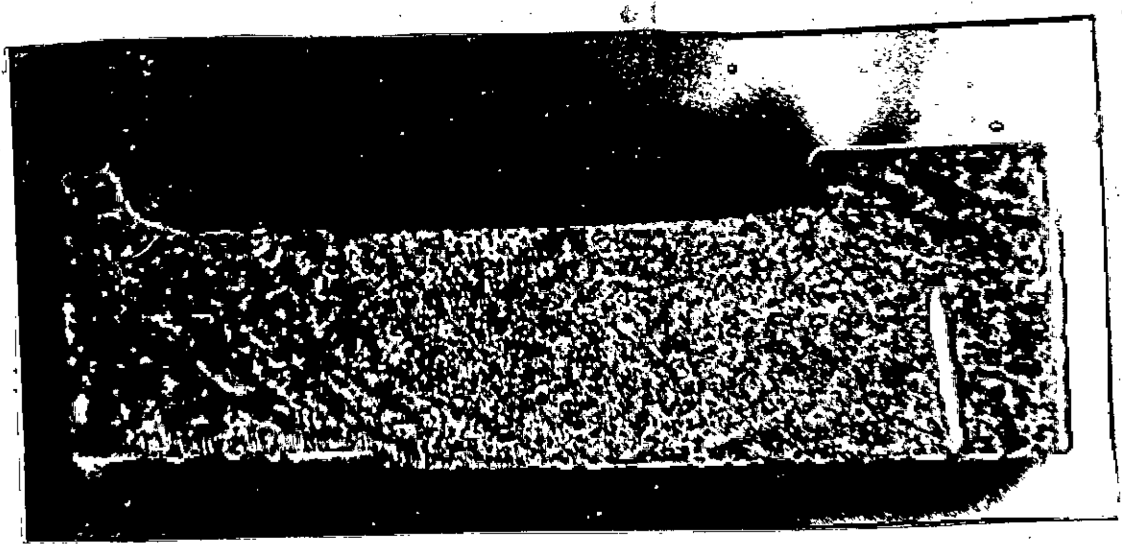
(b) Tool : Copper

(c) Tool : Mild steel

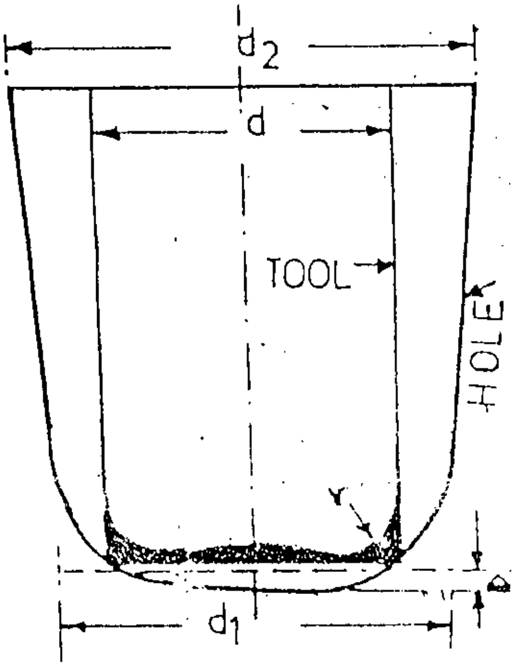


(d) Tool ; Cast iron

Fig - 27 Tool wear and hole oversize produced on Mild steel work material machined by different electrodes



(e) Tool : Stainless steel



(f) Schematic representation of tool wear (dark area) and over size of the hole .

Fig - 27 Tool wear and hole oversize produced on Mild steel work material machined by different electrodes

But in the case of stainless steel, the surface was flat but the side taper was present Fig 27e. It was not desirable. This offer due to low conductivity of heat, the particles which eroded from the electrode contain large amount of energy, impinging on the side and melted the particles as fact as possible. The corner also have a large radii owing to low resistance to debris movement. The machining surface by mild steel and cast iron was not also flat but surface was like as machining by brass electrode. The corner radii was not minimum for inefficient conduction at a corner. So, for the accurate and minimum taper on the machining surfaces copper electrode is better than other electrodes.

5.8 SURFACE FINISH (SF)

It was observed that the surface produced by EDM process at long time duration was highly heterogeneous as shown in Fig. 25. The craters with spilled pool of metal having ineffective expulsion of molten metal from craters indicates the thermal nature of erosion in molten state. Roughness increased with increase in duration time. As the discharge current was increased, the applied erosive power led to greater MRR and hence a rougher surface was form on the machining surface. The average roughness value was minimum Table-8. When brass electrode was used for different job materials, the particles which eroded from brass electrode were very smaller than other electrode particles, Which resulted in smaller craters or bar. Thus led to lower surface roughness of the job surface and its value is about 11.06μm Ra. This value is followed by copper electrode about 12.67μm Ra. The eroded particles were removed as quickly after their formation and therefore it cause lower deposition on the job surface. This led to smoother surface finish.

Table-8 and Fig.28 show the lowest roughness value obtained by using brass electrode and maximum value obtained by cast iron in different cases. In the cast of cast iron the particles, which were eroded from electrode contained lower energy were not able to fully melt the machining particles. Therefore it were not remove by dielectric fluid and the next particles are also impinging on the partially melted particles which led to deposit the particles on the job surface. Therefore a rougher surface form on the machining surface. So those electrode material which were highly conductive are suitable for good surface finish. This experiment shows that copper and brass were good electrode for obtaining good surface roughness than other electrodes.

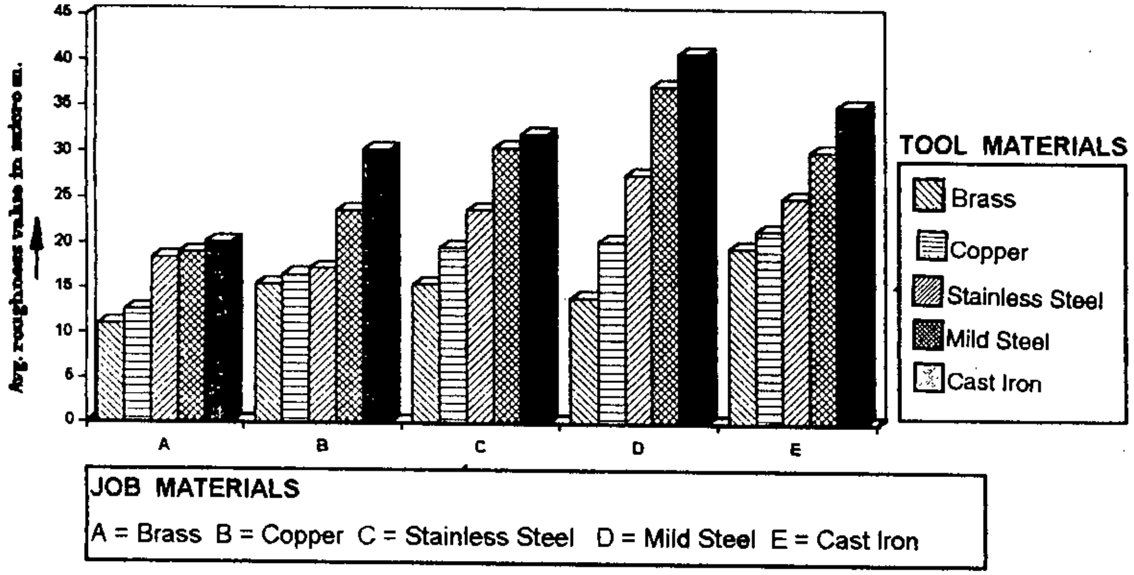


Fig.28 : Surface roughness value of machining surface using by different electrodes

CHAPTER SIX

COST ANALYSIS

6.1 COST FACTORS :

Manufacturing costs of a product consist of the following:

- *i. Direct Materials cost*
- *ii. Direct labour cost*
- *iii. Manufacturing overhead.*

Direct materials costs are the cost for materials that are directly traceable to the finished product.

Direct labour cost in all factory labour identifiable with the conversion of materials into finished goods and usually includes only those people who work directly on the product or on machines that produce it. Manufacturing overhead, some times referred to as indirect manufacturing cost , includes such items as indirect labour, indirect materials, supplies, utilities used in production, taxes, insurance, repairs, maintenance, and depreciation of plant and equipment.

Besides administration, selling and distribution, transportation and finance expenses are common to all manufacturing firms.

6.2 TOTAL COST :

If production cost and administration, selling and distribution and finance expenses are added together, the resulting figure is known as Total cost. To Summarize[29] :

Direct Materials cost :		*********
Add	Direct Labour	*********
Add	Direct Expenses	*********
Gives :	**PRIME COST**	*********
Add	Factory Indirect Expenses	*********
Gives :	**PRODUCTION COST**	*********
Add	Administration Expenses	*********
Add	Selling and Distribution Expenses	*********
Add	Finance Expenses	*********
Gives :	**TOTAL COST**	*********

Table 13 is a list of typical types of expenses found in a manufacturing firm. These can be analyzed as to whether they are direct Materials, Direct labour, Direct Expenses, Factory Indirect Expenses, Administration Expenses, Selling and Distribution Expenses, or Finance Expenses.

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TABLE-13 : Cost Analysis [29]

.Cost	Cost analysis
1. Raw materials for good identifiable with product made	Direct Material
2. Rent of Factory Buildings	Factory Indirect Expenses
3. Salesmen's salaries	Selling and Distribution
4. Wages of Machine operators in Factory.	Direct labour.
5. Wages of Accounting Machine operators in office.	Administration Expenses.
6. Depreciation of machines in Factory.	Factory Indirect Expenses
7. Depreciation of type writers in office.	Administration Expenses
8. Depreciation of Fixture in show room.	Selling and Distribution
9. Foreman's wages in Factory	Factory Indirect Expenses.
10. Royalty paid for each item manufactured.	Direct Expenses
11. Work Manager's salary : 3/4th of the time in the factory and 1/4th of the time in general administration of the firm.	3/4 Factory Indirect Expenses and 1/4 Administration Expenses
12. Row materials Incorporated in goods sold but tool difficult to trace to the goods being made.	Indirect Expenses.
13. Depreciation of Motor vehicles used for delivery of finished goods to customers.	Selling and Distribution Expresses

TABLE-13 : Cost Analysis [29] (Contd.)

Cost	Cost analysis
14. Interest on Bank over draft	Finance Expresses
15. Discounts allowed	Finance Expenses
16. Company secretary's salary	Administration Expresses
17. Advertising	Selling and Distribution Expresses.
18. Wages of staff of canteen used by factory staff only	Factory Indirect Expresses
19. Cost of hinging special machinery for use in manufacturing one special item.	Direct Expresses

6.3 STANDARD TIME AND MACHINING TIME :

Standard time is the time required for machining a work piece in accordance with the capacities of the machine tools and if up to date machining methods are employed on the basis of progressive engineering technique and the experience of innovators of production.

The standard time (per piece) is determined from the following formula :

$$T_p = T_m + T_h + T_s + T_f$$

Where T_p = Standard time (per picee) min.

T_m = Machining time, min

T_h = Handling time, min

T_s = Servicing time, min

T_f = Fatigue allowance, min.

T_m is the time, during which machining is being performed to change the size and form or the state of the workpice surfaces.

T_h is the time required to control the machine tool, for loading and unloading the workpice to make measurements and for advancing and retracting the tool for certain elements.

The sum of T_m+T_h is called the cycle time.

T_s is the time required for all types of servicing and maintainnce during operation (cleaning, holding the work piece , and electrode etc.) as well as time required for changing electrodes and in grinding, polishing for flat surface of electrode, T_s is expressed in percent of the T_m.

T_f is the time required for rest and personal needs of the operator, is provided for all kinds of jobs, T_f is also expressed in percent of the cycle time.

For lot production :
20 - 40% of Tp = Machining time (For Lathe and Grinding machine)
60-80 % of Tp = Machining time (For EDM machine)
6 - 8% of Tp = Time required for rest
2 - 4 % of Tp = Time required for adjustment

6.4 ASSUMPTIONS IN COST ANALYSIS :

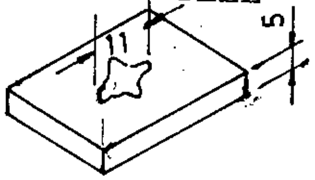
The real situation, the market demand, the price of raw materials, the production rate, etc., may vary due to some unavoidable circumstances. So, actual cost analysis is not an easy task. In the present context, it is possible to analyze the costs under some limited conditions or assumptions. The following factors are to be considered during the project work.

(i) *Market demand*
(ii) *Cost of raw materials*
(iii) *Labour rate*
(iv) *Production rate*
(v) *Bank interest*
(vi) *Building rent*
(vii) *Selling & Administration cost*
(viii) *Selling price of products*
(ix) *Prices of machinery's and equipment.*

Here cost analysis is practiced only for low production cost will be met by which type of electrode use.

6.5 COST OF UNIT VOLUME OF METAL REMOVAL BY EDM PROCESS IN FINISH CUT USING DIFFERENT ELECTRODES

Here production cost of a cavity in the EDM process has been determined. The time required for machining as mentioned below are determined through experiment while the cost estimates are done as per the BITAC's approved rate for various operations. Data for cost estimation for a combination of mild steel as work material and different electrodeare given in below.

Work material	**MILD STEEL**				
Work piece configuration					
Power supply	13.5VA				
Electrode materials	Copper	Brass	Cast iron	Stainless steel	Mild steel
Electrode size (mm) (L x D)	180 X 11				
Dielectric type	Kerosene				
Pressure	12 psi				
Operation type	Finishing				
Voltage	220V				
Current	0.4~0.5A				
Polarity on electrode	(-ve)	(-ve)	(-ve)	(-ve)	(-ve)
Material removal rate (mm^3 / min.)	0.89652	0.96973	0.83362	0.55251	0.39597
Machining time (hr-min.)	8-50	8-10	9-30	14-20	20-00
Surface roughness (µm Ra)	19.55	15.44	31.95	23.80	30.50
Wear ratio	0.2934:1	0.914:1	0.369:1	0.3936:1	0.703:1
Time required to make electrode (min.)	60	55	77	66	70
Set up time (min)	20	20	20	20	20

COST CALCULATION :

1. For copper electrode :

i. Electrode cost (used) :

Volume of electrode = $\Pi / 4 \times d^2 \times l$

Where

V = Volume

Dia. of electrode (d) = 11 mm

Length of electrode (l) = 0.65 mm

V $= \Pi/4\,(11)^2 \times 0.65\ \text{mm}^3$

$= \Pi/4\,(11)^2 \times 0.65\ \text{mm}^3$

$= 61.77156\ \text{mm}^3$

$= 0.06177156\ \text{cm}^3$

Specific weight of electrode = 0.00893 Kg/cm^3

Weight of electrode = Volume of electrode x sp. wt. of electrode

= 0.06177156 x 0.00893

$= 5.5162 \times 10^{-4}$ Kg

Electrode lost (25%) $= 5.5162 \times 10^{-4} \times 25\%$

$= 1.379 \times 10^{-4}$ Kg

Total weight of electrode $= 5.5162 \times 10^{-4} + 1.379 \times 10^{-4}$

$= 6.895 \times 10^{-4}$ Kg

Cost of copper /Kg = 310 TK

Cost of electrode (used) $= 6.895 \times 10^{-4} \times 310$

= TK 0.21375

ii. Electrode machining cost:

Approximate machining time :

Turning	10 min.
Milling	30 min.
Grinding	20 min.
Total time	60 min.

Actual total machining time required for making an electrode

= 60/0.3

= 200 min.

(As machining time = 30% of total time)

Lathe machine OH = TK 40/ hr

Milling machine OH = TK 60/ hr

Grinding machine OH = TK 50/ hr

Factory OH = TK 50/hr

Direct labour = TK 20/hr

Cost of machining copper electrode

= (200/ 60) x (40 + 60 + 50 + 50 +20)

= TK 733.33

Cost of machining copper electrode (used) = (733.33 / 180) x 0.65

= TK 2.65

iii. Job machining cost :

Initial volume of the equivalent cavity $= \Pi / 4 \times d^2 \times l$

Where

V = Volume

Dia. of electrode (d) = 11 mm

Length of electrode (l) = 5 mm

$$V = \Pi / 4 \, (11)^2 \times 5 \ \text{mm}^3$$

$$= 475.165 \ \text{mm}^3$$

Area of slot on the electrode (for one slot)

$= 10.35 \ \text{mm}^2$

Using $A = \beta r^2$

Here β is in radian

Where A = Area of a sector of a circle

Radius (r) = 5.5 mm

Central angle $2\beta = (2 \times \Pi) / 5$ radian (72^0)

Area of slot on the electrode (for 4 slot)

= 10.35 x 4 mm^2

= 41.4 mm^2

Total volume of slot on the electrode = 41.4 x 5 mm^3

= 207 mm^3

Final volume of the form cavity = (475.17 - 207) mm^3

= 268.16 mm^3

Machining time : 530 min.

Electrode set up time : 20 min.

Total time : 550 min.

Total actual machining time required = 550/ 0.7

= 785.72 min.

(As machining time = 70% of total time for EDM m/c)

EDM machine OH = TK 120/hr

Factory OH = TK 50/hr

Direct labour = TK 20 /hr

Cost of machining by EDM process = (785.72/60) X (120 + 50 + 20).

(using Copper electrode) = TK 2488.1

Total cost of making a cavity of 268.165 mm^3

= Cost of electrode material + cost of electrode machining +

+ cost of machining by EDM process

= 0.21+ 2.65 + 2488.1

= TK 2490.96

Actual cost of unit volume of metal removal by copper electrode

= Tk 2489.7/ 268.16 per mm^3

= Tk 9.289 per mm^3

= TK 9289 per cm^3

2. For Brass electrode :

i. Electrode cost (used) :

Volume of electrode = $\Pi/4 \times d^2 \times l$

Where

V = Volume

Dia. of electrode (d) = 11 mm

Length of electrode (l) = 2.17 mm

V = $\Pi/4 (11)^2 \times 2.17$ mm^3

= $\Pi/4 (11)^2 \times 2.17$ mm^3

= 206.22 mm^3

= 0.20622 cm^3

Specific weight of electrode = 0.00824 Kg/cm^3

Weight of electrode = Volume of electrode x sp. wt. of electrode

= 0.20622 x 0.00824

= 1.6992×10^{-3} Kg

Electrode lost (25%) = $1.6992 \times 10^{-3} \times 25\%$

= 4.248×10^{-4} Kg

Total weight of electrode = $1.6992 \times 10^{-3} + 4.248 \times 10^{-4}$

= 2.1241×10^{-4} Kg

Cost of brass /Kg = 310 TK

Cost of electrode (used) = $2.1241 \times 10^{-4} \times 310$

= TK 0.6584

ii. Electrode machining cost:

Approximate machining time :

Turning	8 min.
Milling	25 min.
Grinding	17 min.
Total time	50 min.

Actual total machining time required for making an electrode

= 50/0.3

= 166.67 min.

(As machining time = 30% of total time)

Lathe machine OH = TK 40/ hr

Milling machine OH = TK 60/ hr

Grinding machine OH = TK 50/ hr

Factory OH = TK 50/hr

Direct labour = TK 20/hr

Cost of machining brass electrode

= (166.67 / 60) x (40 + 60 + 50 + 50 +20)

= TK 611.1

Cost of machining brass electrode (used) = (611.1 / 180) x 2.17

= TK 7.36

iii. Job machining cost :

Machining time : 490 min.

Electrode set up time : 20 min.

Total time : 510 min.

Total actual machining time required = 510/ 0.7

= 728.57 min.

(As machining time = 70% of total time for EDM m/c)

EDM machine OH = TK 120/hr

Factory OH = TK 50/hr

Direct labour = TK 20 /hr

Cost of machining by EDM process = (728.56 /60) X (120 + 50 + 20)

(using brass electrode) = TK 2307.14

Total cost of making a cavity of 268.16 mm^3

= Cost of electrode material + cost of electrode machining +

\+ cost of machining by EDM process

= 0.6584+ 7.36 + 2307.14

= TK 2315.16

Actual cost of unit volume of metal removal by brass electrode

= Tk 2314.23 / 268.16 per mm^3

= Tk 8.335 per mm^3

= TK 8335 per cm^3

3. For cast iron electrode :

i. Electrode cost (used) :

Volume of electrode = $\Pi/ 4 \times d^2 \times l$

Where

V = Volume

Dia. of electrode (d) = 11 mm

Length of electrode (l) = 0.75 mm

V $= \Pi/ 4 (11)^2$ x 0.75 mm^3

$= \Pi/4 (11)^2$ x 0.75 mm^3

= 71.27488 mm^3

= 0.07127488 cm^3

Specific weight of electrode = 0.00781 Kg/cm^3

Weight of electrode = Volume of electrode x sp. wt. of electrode

= 0.07127488 x 0.00781

= 5.5665 x 10^{-4} Kg

Electrode lost (25%) = 5.5665 x 10^{-4} x 25%

= 1.3916 x 10^{-4} Kg

Total weight of electrode = 5.5665 x 10^{-4} + 1.3916 x 10^{-4}

= 6.9583 x 10^{-4} Kg

Cost of cast iron /Kg = 30 TK

Cost of electrode (used) = 6.9583 x 10^{-4} x 30

= TK 0.021375

ii. Electrode machining cost:

Approximate machining time :

Turning	12 min.
Milling	40 min.
Grinding	25 min.
Total time	77 min.

Actual total machining time required for making an electrode

= 77 /0.3

= 256.67 min.

(As machining time = 30% of total time)

Lathe machine OH = TK 40/ hr

Milling machine OH = Tk 60/ hr

Grinding machine OH = TK 50/ hr

Factory OH = TK 50/hr

Direct labour = TK 20/hr

Cost of machining cast iron electrode

= (256.67 / 60) x (40 + 60 + 50 + 50 +20)

= TK 941.123

Cost of machining cast iron electrode (used) = (941.123 / 180) x 0.75

= TK 3.92

iii. Job machining cost :

Machining time : 570 min.

Electrode set up time : 20 min.

Total time : 590 min.

Total actual machining time required = 590/ 0.7

= 842.85 min.

(As machining time = 70% of total time for EDM m/c)

EDM machine OH = TK 120/hr

Factory OH = TK 50/hr

Direct labour = TK 20 /hr

Cost of machining by EDM process = (842.85 /60) X (120 + 50 + 20)
(using cast iron electrode) = TK 2669.1

Total cost of making a cavity of 268.16 mm^3

= Cost of electrode material + cost of electrode machining +
+ cost of machining by EDM process
= 0.021+ 3.92 + 2669.1
= TK 2672.96

Actual cost of unit volume of metal removal by CI electrode

= Tk 2671.53 / 268.16 per mm^3
= Tk 9.9678 per mm^3
= TK 9967 per cm^3

4. For Stainless steel electrode :

i. Electrode cost (used) :

Volume of electrode = $\Pi/4 \times d^2 \times l$

Where

V = Volume

Dia. of electrode (d) = 11 mm

Length of electrode (l) = 0.56 mm

$$
\begin{aligned}
V &= \Pi/4\,(11)^2 \times 0.56 \ mm^3 \\
&= \Pi/4\,(11)^2 \times 0.56 \ mm^3 \\
&= 53.2165 \ mm^3 \\
&= 0.0532165 \ cm^3
\end{aligned}
$$

Specific weight of electrode = 0.0079 Kg/cm^3

Weight of electrode = Volume of electrode x sp. wt. of electrode

= 0.0532165 x 0.0079

= 4.24×10^{-4} Kg

Electrode lost (25%) = $4.24 \times 10^{-4} \times 25\%$

= 1.053×10^{-4} Kg

Total weight of electrode = $4.24 \times 10^{-4} + 1.053 \times 10^{-4}$

= 5.2554×10^{-4} Kg

Cost of stainless steel /Kg = 220 TK

Cost of electrode (used) = $5.2554 \times 10^{-4} \times 310$

= TK 0.1156

ii. Electrode machining cost:

Approximate machining time :

Turning	11 min.
Milling	33 min.
Grinding	22 min.
Total time	66 min.

Actual total machining time required for making an electrode

= 66 / 0.3

= 220 min.

(As machining time = 30% of total time)

Lathe machine OH = TK 40/ hr

Milling machine OH = TK 60/hr

Grinding machine OH = TK 50/ hr

Factory OH = TK 50/hr

Direct labour = TK 20/hr

Cost of machining stainless steel electrode

= (220 / 60) x (40 + 60 + 50 + 50 +20)

= TK 806.67

Cost of machining stainless steel electrode (used) = (806.67 / 180) x 0.56

= TK 2.52

iii. Job machining cost :

Machining time : 860 min.
Electrode set up time : 20 min.

Total time : 880 min.

Total actual machining time required = 880 / 0.7

= 1257.14 min.

(As machining time = 70% of total time for EDM m/c)

EDM machine OH = TK 120/hr
Factory OH = TK 50/hr
Direct labour = TK 20 /hr

Cost of machining by EDM process = (1257.14 /60) x (120 + 50 + 20)
(using stainless steel electrode) = TK 3980.95

Total cost of making a cavity of 268.16 mm^3

= Cost of electrode material + cost of electrode machining +

\+ cost of machining by EDM process

= 0.1156 + 2.51 + 3980.95

= TK 3983.57

Actual cost of unit volume of metal removal by S.S electrode

= Tk 3983.57 / 268.16 per mm^3

= Tk 14.855 per mm^3

= TK 14855 per cm^3

5. For Mild steel electrode :

i. Electrode cost (used) :

Volume of electrode = $\Pi/4 \times d^2 \times l$

Where

V = Volume

Dia. of electrode (d) = 11 mm

Length of electrode (l) = 0.68 mm

$$V = \Pi/4\,(11)^2 \times 0.68 \text{ mm}^3$$

$$= 64.623 \text{ mm}^3$$

$$= 0.064623 \text{ cm}^3$$

Specific weight of electrode = 0.00785 Kg/cm^3

Weight of electrode = Volume of electrode x sp. wt. of electrode

= 0.064623 x 0.00785

= 5.073×10^{-4} Kg

Electrode lost (25%) = $5.073 \times 10^{-4} \times 25\%$

= 1.2682×10^{-4} Kg

Total weight of electrode = $5.073 \times 10^{-4} + 1.2682 \times 10^{-4}$

= 6.341×10^{-4} Kg

Cost of mild steel /Kg = 35 TK

Cost of electrode (used) = $6.341 \times 10^{-4} \times 35$

= TK 0.02375

ii. Electrode machining cost:

Approximate machining time :

Turning	12 min.
Milling	35 min.
Grinding	23 min.
Total time	70 min.

Actual total machining time required for making an electrode

= 70/0.3

= 233.33 min.

(As machining time = 30% of total time)

Lathe machine OH = TK 40/ hr

Milling machine OH = TK 60 / hr

Grinding machine OH = TK 50/ hr

Factory OH = TK 50/hr

Direct labour = TK 20/hr

Cost of machining mild steel electrode

= (233.33 / 60) x (40 + 60 + 50 + 50 +20)

= TK 855.56

Cost of machining mild steel electrode (used) = (855.56 / 180) x 0.68

= TK 3.23

iii. Job machining cost :

Machining time : 1200 min.

Electrode set up time : 20 min.

Total time : 1220 min.

Total actual machining time required = 1220 / 0.7
= 1742.86 min.
(As machining time = 70% of total time for EDM m/c)
EDM machine OH = TK 120/hr
Factory OH = TK 50/hr
Direct labour = TK 20 /hr

Cost of machining by EDM process = (1782.87 / 60) X (120 + 50 + 20)
(using mild steel electrode) = TK 5519.1

Total cost of making a cavity of 268.16 mm^3
= Cost of electrode material + cost of electrode machining +
+ cost of machining by EDM process
= 0.0237+3.23 +5519.1
= TK 5522.1

Actual cost of unit volume of metal removal by M.S. electrode
= Tk 5522.1 / 268.16 per mm^3
= Tk 20.582 per mm^3
= TK 20582 per cm^3

From this cost analysis it is found that cost is inversely proportional to metal removal rate i:e directly proportional to machining time Fig 29 . It is due to fact that the electrode material and its machining cost are negligible as compare to its machining cost by EDM process. Since brass electrode remove higher metal than other electrodes, so low cost incurred in the case of brass electrode. It was followed by copper, cast iron, stainless steel and mild steel electrode Fig 30. In this project work finish cut was used due to machine constant. So, material removal rate was very low. This led to maximum operating time for making a cavity, as a result production cost was also very high. But it did not influence the relative costs incurred by different electrode and job material combinations. The absolute costs could be appreciably lowers by rough cuts as well as finish cuts if the machine work at perfect working conditions.

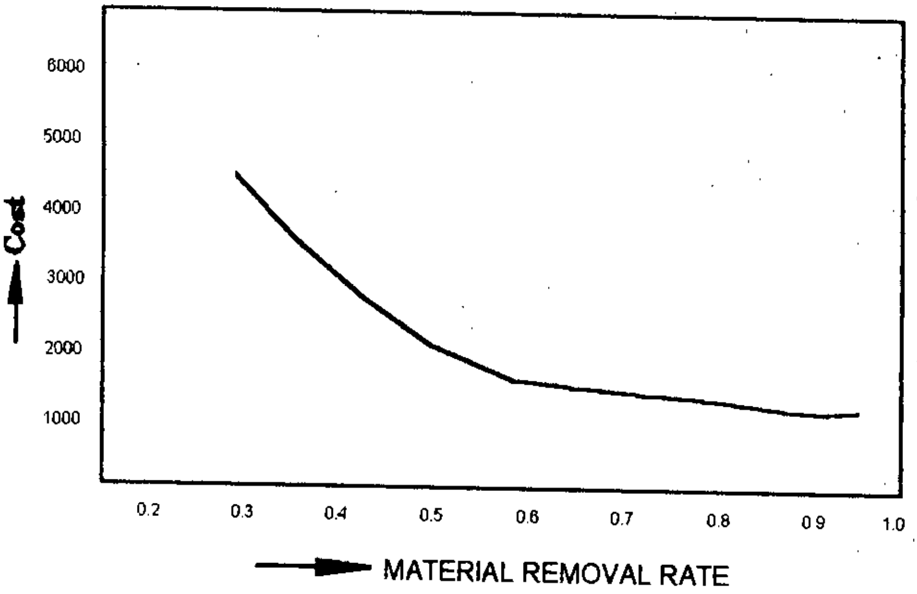


Fig. 29 : Average cost vs. Material Removal Rate

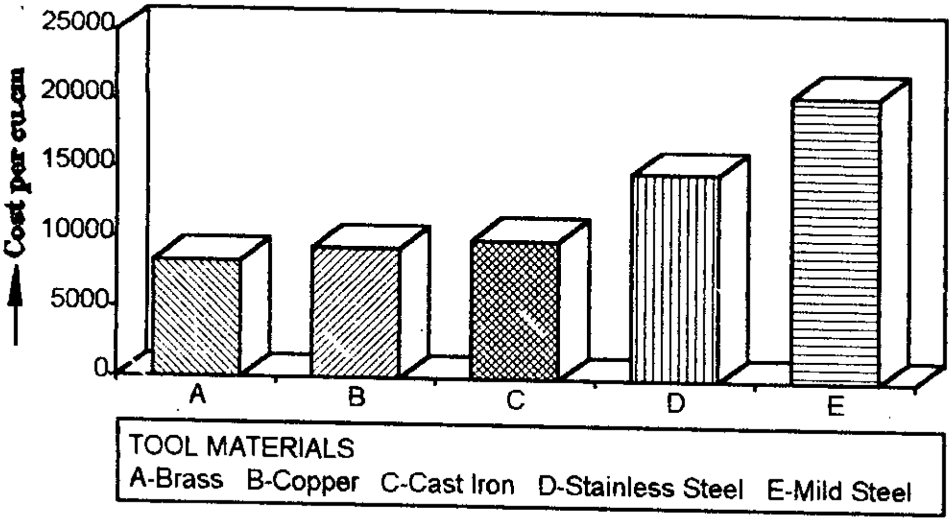


Fig. 30 : Comparative Cost data for machining mild steel by different electrodes

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATION FOR FUTURE STUDY

7.1 Conclutions:

From the experiment results and analysis, it can be concluded that

(1) Brass electrode is suitable for low melting point material and copper electrode is suitable for higher melting point materials.

(2) Maximum recast layer are formed in the case of copper electrode. Due to eroded having high density of heat energy and these particles are easily able to enter maximum thickness of job material.

(3) Copper electrode form a fine grain structure on the machining surface.

(4) Smaller micro-size cavity form in the case of brass electrode . So, higher surface finish are obtained by this electrode .

(5) Convex surface form on the machining surface in the case of brass electrode and also hole over size is occur . This phenomenon occur due to sparking incident at the side surface.

(6) To avoid excessive melting lower duration should be used .

(7) At higher duration there is considerable damage to the machining material including of the surface.

(8) For rough cut higher duration should be used .

(9) Poor surface finish obtain in the case of cast iron , mild steel electrode .

(10) Good surface finish is also occurred in the case of stainless steel electrode but material removal rate is vary low at the same condition with other electrode.

(11) Low cost meet in the case of brass electrode , which follows by copper electrode . so, when cost is considerable then brass and cooper can be considered.

(12) Material removal rate can be change by chaining polarity of the electrode.

7.2 RECOMMENDATION FOR FUTURE STUDY

The work performed had various limitations due to the scope of the tests. It is believed that a wider scope for the selection of a proper electrode remains unexplored. It should therefore be mentioned that the investigation for the selection of appropriate electrodes for various applications should be continued and all the possible variables should be studied. The following recommendations are made for further research to find out more appropriate electrode .

1. *Influenced of variation of melting points of electrode on MRR and tool wear.*
2. *Influenced of current densities on the MRR, tool wear and surface roughness.*
3. *Influenced of uneven heating of the quality on machined surface.*
4. *Influenced of different fluid flushing system of dielectric fluid on the efficiency of the EDM process.*
5. *Behavior of heat effected zone due to influence of the variation of current .*
6. *Behavior of recast layer (RCL) with the variation of the process parameters such as P, I, V , dielectric fluid flushing etc.*

7. *The thin and softened HAZ is difficult to be observed using the conventional metallurgy microscope so electron microscope could be used to thoroughly study the nature of the HAZ.*
8. *Influenced of the gap between tool and job material during sparking on the process parameters.*

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Table-14 WEAR OF DIFFRERENT ELECTRODES USED ON DIFFERENT JOB MATERIALS (mm^3)

Time(min)	Job material	Tool Materials				
		Copper	Brass	Stainless-steel	Mild-steel	Cast-iron
15	Brass	3.698250	13.79220	3.691545	4.605900	3.691500
30		8.321250	27.58440	6.460215	10.13310	8.305950
45		12.01965	40.45725	9.228870	14.73915	11.99760
60		16.64250	54.24945	11.99751	19.34505	16.61190
75		21.26565	68.04180	15.68908	23.95110	21.22635
90		24.96390	81.83415	18.45774	28.55700	25.84080
105		28.75230	95.62635	21.22639	34.08405	29.53245
120		33.28515	108.4990	23.99506	38.69010	34.14675
135		36.98355	121.3719	27.68656	43.29615	38.76120
150		40.68195	135.1642	30.45525	47.90205	42.45270
165		44.38035	148.0371	33.22396	53.42925	47.06730
180		49.00335	161.8290	36.91548	58.03530	52.60485
195		52.70160	175.6215	39.68413	62.64120	57.21885
210		56.49000	189.3240	42.45280	67.24725	61.83345
225		61.02285	202.2870	45.22051	72.77430	67.37070

Table-15 WEAR OF DIFFRERENT ELECTRODES USED ON DIFFERENT JOB MATERIALS (mm^3)

Time(min)	Job material	Tool Materials				
		Copper	Brass	Stainless-steel	Mild-steel	Cast-iron
15	Copper	3.698250	12.87270	4.61430	5.52705	5.53650
30		7.396650	26.66505	10.1517	11.9754	11.5245
45		10.17045	39.53775	15.6885	17.5020	16.6110
60		13.86885	52.41060	22.1490	22.1070	21.2250
75		17.56710	65.28330	27.6855	27.6345	26.7630
90		20.34090	78.15618	32.3010	33.2520	31.3770
105		24.93930	91.94845	37.83750	38.6895	36.9150
120		27.73770	95.98212	43.37550	44.2155	42.4515
135		39.51135	117.6939	49.83450	49.7430	47.0670
150		34.20975	130.56675	55.46250	55.2705	52.6035
165		38.80815	144.35895	60.99105	61.7190	58.1415
180		40.68195	157.23150	65.52450	67.2450	62.7555
195		44.38020	169.18500	71.06100	72.7725	68.2935
210		47.15415	182.05650	77.52150	78.3000	73.8300
225		50.85240	194.93850	83.05950	83.8275	78.4440

APPENDIX-A

Table-16 WEAR OF DIFFRERENT ELECTRODES USED ON DIFFERENT JOB MATERIALS (mm^3)

Time(min)	Job material	Tool Materials				
		Copper	Brass	Stainless-steel	Mild-steel	Cast-iron
15	Cast Iron	4.62285	18.38955	4.61430	5.52705	4.6143
30		8.32125	34.94040	9.22875	11.0541	9.228750
45		12.9442	50.57160	13.8432	16.5813	14.76615
60		16.6425	65.28330	18.4576	22.1083	19.38060
75		21.2655	78.15615	23.0721	29.4778	24.91785
90		24.9639	91.02885	27.6865	35.9262	29.53230
105		28.6623	105.7489	32.3010	42.3744	34.14675
120		33.2851	120.4524	36.9154	49.7439	39.68400
135		36.9835	134.2446	42.4527	55.2709	44.29845
150		40.6819	147.1174	47.0671	62.6404	48.91290
165		45.3048	159.9903	51.6816	69.0888	53.52735
180		49.0032	172.8631	56.2960	75.5371	59.01975
195		52.7016	184.8163	60.9105	81.9853	63.67905
210		56.4000	196.7695	65.5249	88.4337	68.29365
225		60.0984	208.7229	71.0623	94.8819	72.90795

Table-17 WEAR OF DIFFRERENT ELECTRODES USED ON DIFFERENT JOB MATERIALS (mm^3)

Time(min)	Job material	Tool Materials				
		Copper	Brass	Stainless-steel	Mild-steel	Cast-iron
15	Mild Steel	3.69825	12.4215	3.69150	3.68400	4.61400
30		8.32050	25.7445	7.38300	7.36800	8.30550
45		12.0195	39.5370	10.1505	2.05350	12.9195
60		15.7170	53.7795	12.9195	14.7375	17.5335
75		19.4160	66.2025	16.6110	18.4230	22.1490
90		24.0390	79.9950	19.3800	22.1070	27.6855
105		27.7365	93.7860	22.1490	26.7135	32.3010
120		31.4355	106.659	24.9165	30.3990	36.9150
135		36.0585	118.612	27.6855	33.1620	41.5290
150		39.7560	129.862	40.3770	36.8460	46.1430
165		44.3790	145.278	34.1475	42.3735	51.6810
180		48.0780	158.148	36.9150	46.9800	56.2950
195		51.7770	171.943	41.5290	50.6640	59.9850
210		55.4745	185.736	45.2205	54.3495	64.6020
225		59.1735	199.527	48.9120	58.9545	69.2160

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Table-18 WEAR OF DIFFRERENT ELECTRODES USED ON DIFFERENT JOB MATERIALS (mm^3)

Time(min)	Job material	Tool Materials				
		Copper	Brass	Stainless-steel	Mild-steel	Cast-iron
15	Stainless Steel	5.54700	12.8715	2.76750	3.68400	3.69150
30		10.1700	25.7445	5.53650	8.29050	8.30550
45		15.7170	39.5370	9.22800	12.8955	12.9195
60		21.2655	52.4100	12.9195	18.4230	17.5335
75		27.7365	67.1220	17.5335	23.0295	22.1490
90		33.2850	79.9950	20.3025	27.6345	26.7630
105		38.8320	93.7860	23.9940	32.2410	32.3010
120		44.3790	106.659	27.6855	36.8460	36.9150
135		49.9275	120.451	32.3010	41.4525	41.5290
150		55.4745	134.244	35.0685	46.0590	46.1430
165		61.0215	147.117	38.7600	51.5850	50.7585
180		65.6445	159.990	43.3755	56.1915	56.2950
195		71.1930	174.702	46.1430	60.7980	60.9105
210		76.7415	188.493	49.8345	64.4820	65.5245
225		82.2885	202.285	52.6035	70.0095	71.0610

APPENDIX-B

Table-19 MATERIAL REMOVAL RATE (MRR) OF DIFFERENT JOB MATERAILS MACHINED BY DIFFERENT ELECTRODES(mm³)

Time(min)	Tool Material	Job Materials				
		Copper	Brass	Stainless-steel	Mild-steel	Cast-iron
15	Brass	18.68385	46.70970	9.34185	12.84510	14.01285
30		37.36770	93.41955	18.6838	25.69035	28.02585
45		56.05170	138.9616	29.1936	39.70335	39.70320
60		74.73555	184.5037	38.5354	52.54845	52.54845
75		92.25180	228.8779	48.8952	64.22595	66.56145
90		112.1034	273.2523	58.0872	78.23895	80.57430
105		130.7724	315.2911	67.7292	91.08405	93.41955
120		149.4712	357.3300	78.1725	102.7615	107.4325
135		168.1552	398.2011	88.7485	117.9423	121.4454
150		186.8257	437.9044	97.9405	131.9551	135.4584
165		204.3553	477.6078	107.432	147.1359	150.6390
180		221.8716	518.4789	114.942	159.9810	164.6520
195		239.3878	557.0145	128.451	173.9940	179.83275
210		255.7365	594.3823	137.799	188.0070	195.01335
225		272.0740	631.7502	148.3036	218.18925	210.19410

Table-20 MATERIAL REMOVAL RATE (MRR) OF DIFFERENT JOB MATERAILS MACHINED BY DIFFERENT ELECTRODES(mm³)

Time(min)	Tool Material	Job Materials				
		Copper	Brass	Stainless-steel	Mild-steel	Cast-iron
15	Copper	11.74215	32.87835	11.74215	11.74215	14.09070
30		23.48445	64.58265	23.48445	23.48445	29.35560
45		35.22675	97.46100	35.22675	35.22675	43.44645
60		48.14340	129.1651	48.14340	46.96905	58.71135
75		59.88570	162.0436	59.88570	58.71135	72.80220
90		71.62800	193.7479	72.80220	70.45365	86.89290
105		83.37030	224.2779	84.54450	81.02175	102.1579
120		95.11260	253.6336	97.46100	92.76405	116.2486
135		106.8549	284.1636	110.3775	104.5063	130.3395
150		117.4228	343.5192	123.2940	116.2486	144.4302
165		129.1651	404.0493	135.0363	126.8167	159.6952
180		140.9076	463.4050	147.9528	138.5590	174.9603
195		152.6497	506.5866	159.6951	150.3013	190.2252
210		163.2286	550.9423	172.6117	162.0436	205.4902
225		174.9603	594.1239	188.6551	201.7125	220.7551

APPENDIX-B

Table-21 MATERIAL REMOVAL RATE (MRR) OF DIFFERENT JOB MATERAILS MACHINED BY DIFFERENT ELECTRODES(mm^3)

Time(min)	Tool Material	Job Materials				
		Copper	Brass	Stainless-steel	Mild-steel	Cast-iron
15	Cast iron	11.720655	31.645650	11.72055	11.72065	15.23685
30		24.613350	62.119500	22.26915	23.44125	30.47370
45		36.334050	93.765300	32.81775	33.98985	45.71055
60		48.054600	124.23900	44.53845	46.88265	62.11950
75		59.775300	155.88480	55.08705	57.43110	77.35635
90		71.496000	186.35850	65.63565	60.15180	92.59320
105		84.388650	216.83250	77.35635	79.70040	107.8300
120		96.109350	246.13380	87.90495	90.24900	124.2390
135		107.83005	290.43555	98.45355	100.7976	139.4758
150		119.55075	348.56505	109.0021	112.5183	154.7127
165		131.27130	407.86680	119.5507	123.0669	169.9495
180		144.16410	452.16840	131.2713	133.6155	184.0143
195		155.88480	496.47015	141.8199	144.1641	199.2511
210		167.60535	539.59965	153.8685	155.8846	213.3160
225		179.32605	567.72930	155.7744	187.5650	227.3808

Table-22 MATERIAL REMOVAL RATE (MRR) OF DIFFERENT JOB MATERAILS MACHINED BY DIFFERENT ELECTRODES(mm^3)

Time(min)	Tool Material	Job Materials				
		Copper	Brass	Stainless-steel	Mild-steel	Cast-iron
15	Mild steel	11.69895	32.75730	5.84940	4.67955	11.69895
30		23.39805	66.68445	11.6989	10.5291	24.56790
45		35.09700	100.6117	17.5485	16.3786	37.43685
60		47.96595	135.7089	23.3980	22.2280	50.30580
75		59.66505	168.4662	29.2476	28.0776	63.17475
90		71.36415	202.3935	35.0971	32.7573	76.04370
105		84.23310	236.3208	40.9465	38.6068	88.91265
120		95.93205	269.0781	46.7961	43.2864	101.7817
135		107.6311	303.0060	52.6456	49.1359	114.6565
150		120.5001	335.7627	59.6650	54.9855	128.6895
165		132.1992	368.5200	65.5146	60.8349	141.5584
180		143.8983	401.2773	71.3641	65.5146	154.4274
195		155.5972	435.2046	77.2137	71.3641	167.2963
210		167.2963	467.9619	83.0632	78.3835	180.1653
225		180.1653	501.8892	87.7428	89.0932	194.2041

APPENDIX-B

Table-23 MATERIAL REMOVAL RATE (MRR) OF DIFFERENT JOB MATERAILS MACHINED BY DIFFERENT ELECTRODES(mm^3)

Time(min)	Tool Material	Job Materials				
		Copper	Brass	Stainless-steel	Mild-steel	Cast-iron
15	Stainless steel	11.72055	65.63565	5.86020	7.03239	11.72055
30		23.44125	98.45355	12.89265	15.2368	25.78545
45		36.33405	130.0993	18.75300	21.0970	38.67810
60		48.05460	160.5730	24.61335	26.9574	52.74285
75		59.77530	188.7025	31.64565	33.9898	65.63565
90		71.49600	203.0043	37.50600	42.1942	78.52830
105		83.21670	216.1339	43.36635	49.2267	91.42110
120		96.10935	228.0913	49.22670	56.2591	104.3137
135		107.8300	242.3931	55.08705	62.1195	117.2065
150		120.7227	256.6947	62.11950	67.9797	131.2713
165		132.4434	284.8243	67.97970	73.8400	144.16414
180		145.3362	296.7819	75.012150	80.8725	157.05675
195		158.2288	307.5673	80.87250	87.9049	169.94955
210		172.2936	325.2091	87.90495	96.1093	182.84220
225		186.3589	332.6544	93.76530	124.314	196.90710