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Advancement in Electric Discharge Machining on metal matrix composite materials in recent: A Review

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Abstract- Existing manufacturing industries are fronting challenges from these advanced nasent materials viz. nano material ,ceramics, super alloys, and metal matrix composites, that are hard and difficult to machine, requiring high accuracy, surface quality excellence which affects and increases machining cost. To meet these tasks, unconventional machining processes are being used to achieve optimum metal removal rate, better surface finish and greater dimensional correctness, with a reduced amount of tool wear. Electric Discharge Machining (EDM), a unconventional process, has a extensive applications in automotive, defense, aerospace and micro systems industries plays an outstanding role in the development of least cost products with more consistent quality assurance. Die sinking EDM, Wire electrical discharge machining (WEDM),Dry EDM, Rotary disk electrode electrical discharge machining (RDE-EDM) are some of the alternates methods of EDM. This paper reviews the recent developments and advances in the field of high performance manufacturing environment using Die Sinking EDM, WEDM, Dry EDM and RDE-EDM. The review is based on prominent academic publications researches.

Index Terms- electro-discharge machining (EDM), die sinking EDM, metal matrix composites, tool wear, MRR.

I. INTRODUCTION

The advanced materials have striking properties i.e., high strength, high bending stiffness, good damping capacity, low thermal expansion, better fatigue characteristics which make them prospective material for modern industrial application. Present manufacturing industries are facing challenges from these advanced materials viz. super alloys, ceramics, and composites, that are hard and difficult to machine, requiring high precision, surface quality which increases machining cost **[1]**. To meet these challenges new processes with advanced methodology and tooling needs to be developed. The conventional machining of such advanced materials are often difficult due to the improved thermal, chemical and mechanical properties of new advanced materials. Conventional machining such as turning, milling and drilling etc shows ineffectiveness in machining of advanced materials, since it results in poor materials removal rate, excessive tool wear and increased surface roughness. Non-Conventional Machining processes are classified according to the type of energy used for the machining of the work materials. i.e. Mechanical Ultrasonic machining(USM), Water jet machining(WJM),Abrasive jet machining (AJM), Thermal Electrical discharge machining(EDM),Electron beam machining (EBM), Laser beam machining (LBM), and Chemical (Chemical machining (CHM) , Photo chemical machining (PCM) **[2]**.The Electric Discharge Machining (EDM), a thermal material removal process, has firmly established its use in the production of forming tools, dies, molds and effectively machining of advanced materials.

A. EDM Overview

In Electrical Discharge Machining the electrode is moved downward toward the work material until the spark gap (the nearest distance between both electrodes) small enough so that the impressed voltage is great enough to ionize the dielectric**[3]**. Short duration discharges (measured in microseconds) are generated in a liquid dielectric gap, which separates tool and work piece.EDM does not make direct contact between the electrode and the work piece where it can eliminate mechanical stresses chatter and vibration problems during machining **[4]**. The material in the form of debris is removed with the erosive effect of the electrical discharges from tool and work piece **[5]**. EDM is often included in the 'non-traditional' or 'non-conventional' group of machining methods together with processes suchas electrochemical machining (ECM), water jet cutting (WJ, AWJ), laser cutting and opposite to the 'conventional' group (turning, milling, grinding, drilling and any other process whose material removal mechanism is essentially based on mechanical forces)

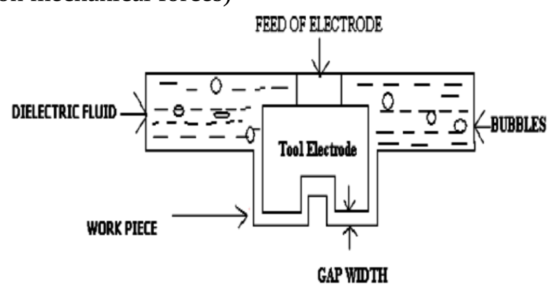

Fig 1.0 Schematic diagram of EDM

EDM is a non-conventional process based on removal of unwanted material in the form of debris from a job piece by means of a chain of recurring electrical discharges (created by electric pulse generators in micro seconds) between a tool called electrode and the work material in the presence of a dielectric fluid(like kerosene and distilled water). The history of EDM begins in 1943, with the creation of its principle by Russian scientists Boris and Natalya Lazarenko in Moscow. They were assigned by the Soviet government to investigate the wear caused by sparking between tungsten electrical contacts, a problem which was particularly critical for maintenance of automotive engines during the Second World War. Putting the electrodes in oil, researchers found that the sparks were more uniform and predictable than in air. They had then the idea to reverse the phenomenon, and to use controlled sparking as an erosion method **[6]**. Lazarenkos developed during the war the first EDM machines, which were very useful to erode hard metals such as tungsten or tungsten carbide. In the 1950's, progress was made on understanding the erosion phenomenon **[7-9]**. During this period industries produced the first EDM machines. Owing to the poor quality of electronic components, the performances of the machines were limited at this time. In 1960's, the development of the semiconductor industry permitted considerable enhancements in EDM machines. Die-sinking machines became reliable and produced surfaces with controlled quality, whereas wire-cutting machines were still at their very beginning. During the following decades, efforts were principally made in generator design, process automatization, servo-control and robotics. Applications in micro-machining became also of interest during the 1980's **[10]**. It is also from this period that the world market of EDM began to increase strongly, and that specific applied EDM research took over basic EDM research**[11]**. Consequently, new methods for EDM process control emerged in the 1990's by using fuzzy control, neural networks, response surface methodology, central composite design, and Taguchi optimization etc.

II. ELECTRICAL DISCHARGE MACHINE (EDM)

In this the basic fundamentals of the EDM Method and the other unconventional methods for material removal are discussed.

A. EDM: Working principle

The material erosion mechanism primarily makes use of electrical energy and turns it into thermal energy through a series of discrete electrical discharges occurring between the electrode and work piece submerged in a dielectric liquid medium **[12]**. The thermal energy generates a channel of plasma between the cathode and anode **[13]** at a temperature in the range of 8000 to 12,000 °C**[14]**. When the pulsating direct current supply occurring at the rate of approximately 15,000–30,000Hz **[15]** is turned off, the plasma channel breaks down. Due to this sudden reduction in the temperature allowing the circulating dielectric fluid to implore the plasma channel and flush the molten material from the pole surfaces in the form of microscopic debris are observed.

Electrical Discharge occurs at higher frequencies since the metal removal rate for each discharge is very less in change in weight. For every pulse, electrical discharge occurs at a particular position where the electrode materials are melted and evaporated and finally ejected in the molten phase (in the form of debris) thus forming small crater on both tool electrode and work piece. The undesirable material is then cooled and re-solidified in the dielectric fluid forming large number of debris particles which will be flushed away from the gap by the flow of dielectric pressure. During each end of the discharge duration, the temperature of the plasma channel and the electrode surfaces that is in contact of the plasma rapidly drops, resulting in the recombination of ions and electrons. For maintaining stability in EDM process, every successive next pulse discharge occurs at a spot distanced sufficiently far from the previous discharge position. The pulse interval (known as pulse off time period) for the next discharge pulse should be not so much long and not too short .If it is long then the plasma channel that is generated by the previous discharge can be fully de-ionized and the dielectric breakdown strength around the previous discharge location can be recovered by the time the next voltage charge is applied and short pulse interval time produces more surface roughness and instability in machining **[16]**.

B. Fundamental EDM Settings

The polarity, pulse duration, pulse interval and peak current are the basic machine settings. These parameters can also be expressed as average current, pulse frequency and duty factor.

i. Average Current

It is the maximum current available for each pulse from the power supply/generator in the circuit. Average current is the average of the amperage in the spark gap measured over a complete cycle.It is calculated by multiplying peak current by duty factor.

Average Current (A) = Duty Factor (%) × Peak Current

ii. Pulse Frequency

It is the number of cycles produced across the gap in one second. The higher the frequency, finer is the surface finish that can be obtained. With an increase of number of cycles per second, the length of the pulse on-time decreases. Short pulse on-times remove very little material and create smaller craters. This produces a smoother surface finish with less thermal damage to the workpiece. Pulse frequency is calculated by dividing 1000 by the total cycle time (pulse on-time+ pulse off-time) in microseconds.

Pulse Frequency (kHz) = 1000/Total cycle time (µs)

iii. Duty Factor

Duty factor is a percentage of the pulse duration relative to the total cycle time. Generally, a higher duty factor means increased cutting efficiency. It is calculated in percentage by dividing pulse duration by the total cycle time (pulse on-time + pulse off-time).

Duty Factor (%) = [Pulse duration (µs)/Total cycle time (µs)] × 100

F.L.Amarim result out the effect of duty cycle on the machining of AMP-8000. The researchers concluded that increase of duty factor increases MRR. This is due to the reason that with increase of duty cycle a black layer was seen on the surface of work material and with further more increase of it, the machining becomes unstable**[32]**.MRR increases with increase in duty factor at constant current constant pulse on time. This is due to the reason that with increase in duty cycle, the intensity of spark increases resulting in higher MRR.

C. Basic EDM Process Parameters

i. Electrical Parameters

Pulse Duration (Ton): It is the duration of time measured in micro seconds. During this time period the current is allowed to through the electrode towards the work material within a short gap known as spark gap. Metal removal is directly proportional to the amount of energy applied during the on time period **[17]**.Pulse duration is also known as pulse on time and the sparks are produced at certain frequency. Material removal rate depends on longer or shorter pulse on time period. Longer pulse duration improves removal rate of debris from the machined area which also effects on the wear behaviour of electrode. As in EDM process erosion takes place in the form of melting and vaporization of both the tool and work material at the same time period, so with longer pulse duration more material has to be melt and vaporize. The substantial crater produced will be broader as comparison to the shorter pulse on time. But, in some experimental research work it has been proved that optimal pulse duration gives higher performance measures **[18]**. It conclude all that MRR cannot be increased by increasing the Pulse on time, a suitable combination of peak current is also needed for increasing rate of removing unwanted material from the work piece. At constant current and constant duty factor, the MRR is decreased with increase in pulse on time **[19]**. This is due to the reason because of short pulses cause less vaporization, whereas long pulse duration causes the plasma channel to expand rapidly. This expansion of plasma channel cause less energy density on the work material, which is not sufficient to melt and vaporize the work material. It was also concluded by the researchers that with increase of pulse duration, surface roughness decreased, hardness of work material, crack length, crack width and the thickness of recast layer increased. The undesirable material is then cooled and re-solidified in the dielectric fluid forming large number of debris particles which will be flushed away from the gap by the flow of dielectric pressure. During each end of the discharge duration, the temperature of the plasma channel and the electrode surfaces that is in contact of the plasma rapidly drops, resulting in the recombination of ions and electrons.

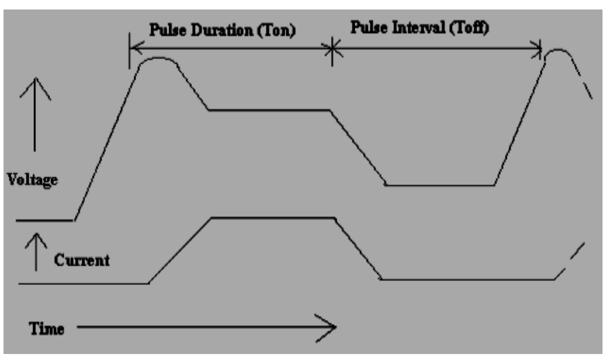

Fig. 2 Actual profile of single EDM pulse (Fuller, 1996)

Pulse Interval (Toff): This parameter is to affect the speed and the stability of the cut. If the off-time is too short, it improves MRR but it will because more sparks to be unstable in the machining zone. Kansal et al.[20] result out that increase in pulse interval time decreases the MRR. Saha et al.[21] reported out that for small value of pulse interval time period, the MRR was low, but with further increase MRR increases.MRR was dropped slowly with increase in pulse interval time. This is due to very short pulse interval the probability of arcing is larger because dielectric in the gap does not recover its dielectric strength.O.A.Abu Zeid investigated the role of voltage, pulse off time in the electro discharge machined AISI T1 high speed steel[22]. The researcher concluded that the MRR is not so much sensitive to pulse interval time changes at low pulse on time in finish machining.

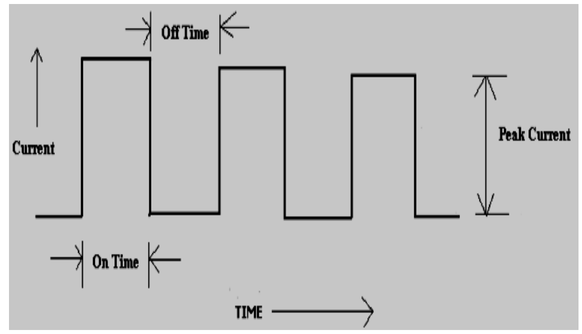

Fig. 3.0 Pulse wave form of pulse generator [28]

Electrode gap (spark gap): It is the distance between the electrode and the part during the process of EDM. An electro-mechanical and hydraulic systems are used to respond to average gap voltage. To obtain good performance and gap stability a suitable gap should be maintained. For the reaction speed, it must obtain a high speed so that it can respond to short circuits or even open gap circuits. Gap width is not measured directly, but can be inferred from the average gap voltage **[23]**.

Polarity: It may be positive or negative connected to tool electrode or work material. Polarity can affect processing speed, finish, wear and stability of the EDM operation. It has been proved that MRR is more when the tool electrodes are connected at positive polarity(+) than at negative terminal(-) .This may be due to transfer of energy during the charging process is more in this condition of machining. When an electrical discharge is generated electrons dispatch from the negative polarity collides with neutral molecules between the work piece and electrode which is responsible for ionization process in EDM. However, ionization is taken because the electron arrives at the positive terminal of the surface. The negative polarity is more desirable as compared to positive polarity **[24]**. The researcher concluded this is because the MRR is higher and better surface finish is produced as MRR is dependent on anode potential drop. It was experimentally worked on the micro slitting on titanium alloy with copper as rotating disk as an electrode. They concluded that MRR was lower with positive polarity of work piece as compared to negative polarity. This is due to the fact that with positive polarity of work piece, the dissociated carbon elements in the dielectric fluid tend to adhere to the anode, which result in forming a recast layer **[25]**.

D. Non Electrical Parameters

Non-electrical parameters such as the Rotational movement of electrode, flushing of dielectric fluid and aspect ratio (tool shape) together play a significant role in delivering optimal performance measures. This section discusses the effects of non-electrical parameters on the various performance measures.

i. Rotation of Tool Electrode

It is the rotational effect of cylindrical (pin shaped) or disc shaped electrode tool measured in revolution/minute. The rotational movement of electrode is normal to the work surface and with increasing the speed, a centrifugal force is generated causes more debris to remove faster from the machining zone.According to Mohan et al. **[18]**, the centrifugal force generated throws a layer of dielectric in to the machining gap, induces an atmosphere for better surface finish, prevent arching and improves MRR. Soni and Chakraverti **[26]** compared the various performance measures of rotating electrode with the stationary electrode. The results concluded an improvement in MRR due to the better flushing action and sparking efficiency with little tool wear but the surface finish was improved.

ii. Injection flushing

Flushing removes eroded particles from the gap for efficient cutting and improved surface finish of machined material. Flushing also enables fresh dielectric oil flow into the gap and cools both the electrode and the work piece. Basic characteristics required for dielectric used in EDM are high dielectric strength and quick recovery after breakdown **[27]**.There variations of EDM processes can be classified according to the type of dielectric fluid used. Most dielectric media are hydrocarbon compounds and water. The hydrocarbon compounds are in the form of refined oil; better known as kerosene. While the fluid properties are essential, the correct fluid circulating methodology is also important. The dielectric fluid not only forms a dielectric barrier for the spark between the work piece and the electrode but also cools the eroded particles between the work piece and the electrode. The pressurized fluid flushes out the eroded gap particles and remove the debris from the fluid medium by causing the fluid to pass through a filter system**[28]**.During the investigation of EDM of Ti 6Al 4V, Chen et al. **[29]** found that the MRR was greater and the relative EWR is lower, when using 16 distilled water as dielectric solution.

iii. Tool Geometry

Tool geometry is concerned with the shape of the tool electrodes.ie. Square, rectangle, cylindrical,circular.etc. The ratio of length /diameter of any shaped feature of material. In case of rotating disk electrode the ratio becomes thickness/diameter. Murali et al **[30]** used graphite foil for straight grooving operation instead of pin shaped electrode. An aspect ratio of 2.3 was achieved by using FAST technique (Foil as tool electrode) which was improved to 8 by implementing GAME (Gravity assisted Micro EDM).Singh et al. **[31]** uses square and rectangular shaped electrodes having aspect ratio of 1.0 and 0.6 for machining 6061Al/Al2O3P composite .It concluded that shape of the electrode effects EWR. The tool having less aspect ratio gave higher value of EWR. Thus with increasing the size of electrode more good performance of ED Machining takes place.

iv. Tool Material (Electrode)

Engineering materials having higher thermal conductivity and melting point are used as a tool material for EDM process of machining . Copper, graphite, copper-tungsten, silver tungsten, copper graphite and brass are used as a tool material (electrode) in EDM. They all have good wear characteristics, better conductivity, and better sparking conditions for machining. Copper with 5% tellurium, added for better machining properties. Tungsten resist wear better than copper and brass .Brass ensures stable sparking conditions and is normally used for specialized applications such as drilling of small holes where the high electrode wear is acceptable (Metals Handbook, 1989). The factors that affect selection of electrode material include metal removal rate, wear resistance, desired surface finish, cost of electrode material manufacture and material and characteristics of work material to be machined.

III. EDM VARIANTS

In die sinking process the tool electrode is the replica of the machined profile of the work material shown in **fig 4.** Die sinking process solves the problem of manufacturing accurate and complex-shaped electrodes of three-dimensional cavities. According to the article “Advancing EDM through Fundamental Insight into the Process” by M. Kunieda Tokyo University of Agriculture and Technology, Japan), B. Lauwers (Katholieke Universities Leuven, Belgium), K.P. Rajukar (University of Nebraska-Lincoln, USA), B.M Schumacher (University of Applied Science St Gallen, Switzerland), the work piece can be formed either by replication of a shaped tool electrode or by 3-Dimensional movement of a simple electrode similar to milling or we can use the combination of both the methods.

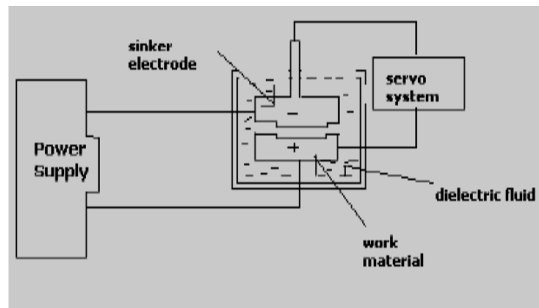

Fig. 4 Schematic diagram of Die-sinking EDM

A number of EDM variations based on this basic configuration have emerged in the industry to cope with the machining of smart materials or super alloys used exclusively in the manufacture of aeronautical and aerospace parts. Wire-cut EDM (WEDM) and Rotary Disk electrode electrical discharge machining process (RDE-EDM) are some of the most favourable variants owing to its ability to machine conductive, exotic and high strength and temperature resistive (HSTR) materials with the scope of generating intricate shapes and profiles **[33].**

A. Wire EDM process

WEDM was first introduced to the manufacturing industry in the late 1960s. In WEDM, material is eroded from the work material by a series of discrete sparks occurring between the work piece and the wire separated by a stream of dielectric fluid, which is continuously fed to the machining zone **[34].** The WEDM process makes use of electrical energy generating a channel of plasma between the cathode and anode **[35],** and turns it into thermal energy at a temperature in the range of 8000–12,000 °C **[36]**. When the pulsating direct current power supply occurring between 20,000 and 30,000 Hz **[37]** is turned off, the plasma channel breaks down.This causes a sudden reduction in the temperature allowing the circulating dielectric fluid to implore the plasma channel and flush the molten particles from the pole surfaces in the form of microscopic debris.

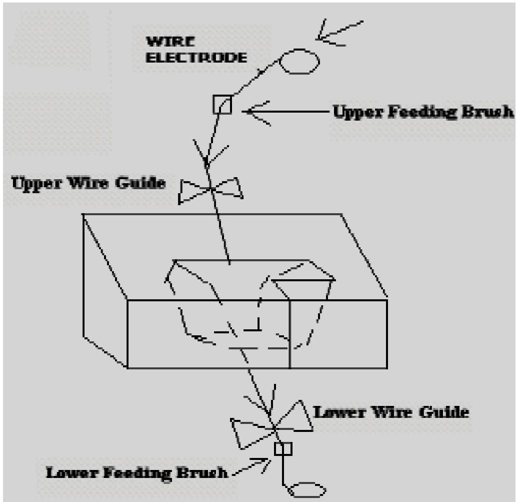

Fig. 5 Schematic diagram of Wire EDM process [2]

i. WEDM process monitoring and control of smart material

Lok et al. **[38]** presented the finding of processing two advanced materials Sialon and Al2O3-TiC by using WEDM. The author has taken MRR and surface finish as output parameters. The surface damage was evaluated by flexural strength data. The variability of flexural strength data was analyzed by weibull stastical method. The mean flexural strength drops from 32% to 67% due to thermal spalling erosion mechanism of wire-cut EDM process. Yan et al**. [39]** machined aluminium matrix composites (Al2O3p/6061 Al) using WEDM. The effect of pulse on time, cutting speed, width of slit, surface roughness was studied. The wire easily got broken while machining Al2O3p/6061 Al. It was observed that that the cutting speed, surface roughness and width of the slit significantly depend upon volume fraction of Al2O3 particles. Less volume percentage of reinforcement increases the surface finish, improves width of slit.Hascaly et al**. [40]** performed an experiment for finding out the machining characteristics of AISI D5 tool steel in WEDM. The author concluded that intensity of process energy affect the surface roughness as well as micro cracking. The wire speed and fluid pressure do not have much influence. Gokler et al**. [41]** experimented to optimized the cutting and offset parameter combination for WEDM process to achieve the desired surface roughness. The author has performed experiments on 1040 steel material of thickness 30, 60 and 80 mm and on 2379 and 2378 steel materials of thickness 30 and 60 mm. It was concluded that increase in the work piece thickness creates better surface roughness characteristic. Tarng et al**. [42]** used a neural network system to determine settings of pulse duration, pulse interval, peak current, open circuit voltage, servo reference voltage,electric capacitance, and table speed for the estimation of cutting speed and surface finish.

ii. Wire breakage in EDM

A wide variety of the control strategies preventing the wire from breaking are built on the knowledge of the characteristics of wire breakage .Saha et al**. [43]** developed a model that predicts the thermal distribution accurately, increase wire velocity and reduction in heat transfer coefficient. He has found that non uniform heating is the most important variable affecting the temperature stress. FE Model would help to prevent wire breakage. Tosun et al. **[44]** found that increasing pulse duration and open circuit voltage increase the wire wear rate.

Whereas the increasing wire speed and dielectric fluid pressure decreases the wire wear. Luo et al. **[45]**claimed that the wire material yielding and fracture contribute to the wire breakage, whilst an increase in temperature aggravates the failure process.

iii. Modelling of WEDM process

Tarng et al.**[42]** formulated a neural network model and simulated annealing algorithm in order to predict and optimize the surface roughness and cutting velocity of the WEDM process when machining of SUS-304 stainless steel materials. T.A. Spedding and Z.Q.Wang **[46]** attempted to model the cutting speed and surface roughness of WEDM process through the response-surface methodology and artificial neural networks (ANNs) and have found that the model accuracy of both the approaches were better. The same authors (T.A. Spedding and Z.G. Wang, 1997) attempted further to optimize the surface roughness, surface waviness and speed of the artificial neural networks that predicted values using a constrained optimization model. Lin et al. **[47]** proposed a control strategy based on fuzzy logic to improve the machining accuracy. Huang and Liao **[48]** presented the use of Grey relational and S/N ratio analyses, for determining the optimal parameters setting of WEDM process.The results showed that the MRR and surface roughness are easily influenced by the table feed rate and pulse on time.

IV. DIE SINKING EDM

A. Introduction

Die sinking electrical discharge machining (EDM) is one of the most widely used techniques for the fabrication of die and mold cavities which are finally used for mass production of metals and polymer products by replication such as die casting, injection molding, etc. In any replication process, it is expected that the quality mold will faithfully duplicate its shape and surface texture.Inaccurate duplications cause problems in assemblies,operations as well as lower the aesthetic view. In die sinking EDM the electrode produces exactly its opposite shape on the work material. For the case of complex shaped mold cavities, the machining effectiveness or performance of die sinking is not uniform all over the machining area.

The machining performance for the intricate areas such as sharp or pointed corner, flat or pointed areas of electrode, is obviously different because of different concentration of heat and current density.The performance of EDM is usually evaluated by the output parameters namely material removal rate (MRR),electrode wear rate (EWR), wear ratio (WR), machined surface roughness, etc.**[49-50]**. Ahsan etal discussed the performance of die sinking EDM due to the shape configuration of the electrode. The effect of electrode shape on material removal rate (MRR), electrode wear rate (EWR), wear ratio (WR), and average surface roughness (Ra) has been investigated for mild steel work material and copper electrode **[51]**.

Adapted from the article “Advancing EDM through Fundamental Insight into the Process” by M.Kunieda(Tokyo University of Agriculture and Technology, Japan), B.Lauwers (Katholieke Universiteit Leuven, Belgium), K.P.Rajukar (University of Nebraska-Lincoln, USA), B.M Schumacher (University of Applied Science St Gallen,Switzerland). The sinking electrical discharge machining is as shown in Figure 2.

The workpiece can be formed either by replication of a shaped tool electrode or by 3-Dimensional movement of a simple electrode similar to milling or we can use the combination of both the methods. Normally we use copper or graphite as the electrode material. The numerical control monitors the gap conditions and synchronously controls the different axes and the pulse generator. The dielectric liquid is filtrated to remove debris particles and decomposition products. Hydrocarbons dielectric is normally used since the surface roughness is better and tool electrode wear is lower compared to the de-ionized water.

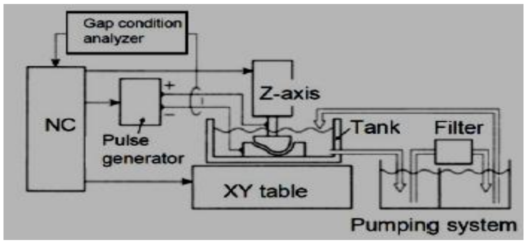

Fig. 6 Sinking Electrical Discharge Machining.

B. Researches in sinking EDM on metal matrix composites

i. SiC/aluminum matrix

Ramulu and Taya investigated machinability of 15 vol.% and 25 vol.% SiC whisker/2124 aluminum matrix (SiCw/Al) composites **[52]**. The material samples were cut at coarse, medium, and fine conditions using copper and brass tools. It was found that material removal rate increases with increase in power of electrode. MRR in 15 vol.% SiCw/2124 Al is >25 vol.% SiCw/2124 Al. Material removal rate obtained by using copper electrode is 5-10% less than that of obtained when using brass electrode. Machining time appears to be higher in 25 vol.% SiCw/Al than in 15% SiCw/Al composite. The micro-hardness tests on SiCw/Al composite have revealed that the machining causes surface softening at slower cutting speed. It was also found that higher cutting speed results in micro-damage in the surface and sub-surface area. However, in the study performance, measures were evaluated only for variation in average current. Effects of variation of other parameters have not been taken into account. Also, machinability of 25 vol.% SiCw/2124 Al was evaluated only for brass electrode, whereas the second sample material was evaluated for both brass and copper electrode. De Silva and Rankine studied the electro-erosion characteristic of SiC/Al and found that the Al matrix surrounding the reinforcing particles was melted **[53].** The SiC particles were then dislodged from the matrix and flushed away by the dielectric fluid **[54]**. Muller and Monaghan presented details and results of an investigation into the machinability of SiC particle reinforced aluminum matrix composites using different nonconventional machining processes such as electro discharge machining, laser cutting and abrasive water jet **[55]**.Objective of the research work was to investigate difference in surface quality, including surface roughness, surface topography, and sub-surface damage of machined workpiece. Furthermore, the effect of the reinforcement on the machining operation was investigated by performing comparative tests on non-reinforced aluminum alloy samples. The results obtained indicate that Al/SiC particle reinforced metal matrix composite (PRMMC) is machinable by using same non-conventional machining processes. The findings show that EDM process is suitable for machining PRMMCs, but the process is very slow. Machining results in a crater-like surface. The size of the craters increases with increased discharge energy. Also, relatively small amount of sub-surface damage is found on the cut surfaces after machining (depending on the chosen machining settings).The research work focuses mainly on influence of reinforcement on surface quality of machined material.Other performance measures have not been taken into account in much detail. Since different machining processes have different setup and different material removal mechanism therefore resulted in different surface integrities.

ii. Other Metal Matrix Composites

One recent work by Ahamed et al. has been found on hybrid-type MMC. Hybrid metal matrix composites are a class of materials, having two or more discrete particulate reinforcements. The objective of the research work was to investigate the effect of machining parameters namely current, pulse on-time, pulse off-time, and flushing pressure on the material removal rate and surface roughness while machining hybrid composites Al–5%SiC–5% B4C and Al–5%SiC–5% glass prepared by stir casting. The effect of inclusion of B4C and glass on machining of aluminum–SiC composite was investigated. Presence of ceramic particulate reinforcements impedes the machining. A trade-off has to be made between the levels of parameters for achieving the combined objective of maximizing material removal and minimizing surface roughness. A fairly long spark is required to remove material which has embedded in it hard particles such as B4C and SiC. Longer spark duration is essential to remove the SiC and glass particles which are, however, easily flushed away by the fluid at a fairly lower pressure of flushing. This is because of the lower density of glass when compared to B4C. The white layer, which is a characteristic of machined surfaces,is seen prominently on both materials.The research work is devoted to find the effect of machining parameters on material removal rate and surface roughness. Electrode wear has not been taken into account in this research work. There is a lot of scope for future research work in EDM of such kind of materials **[56].**

V. MATERIAL REMOVAL MECHANISM (MRM)

It is well established that MRM is the process of transformation of material elements between the work-piece and electrode. These elements diffuse from the electrode to the work-piece and vice versa, and are transported in solid, liquid or gaseous state, and then alloyed with the contacting surface by undergoing a solid, liquid or gaseous phase reaction **[57].**Phase of sparking of MRM (breakdown, discharge and erosion) is highly influenced by the types of eroded electrode and work-piece elements together with disintegrated products of dielectric fluid.

VI. TOOL WEAR

Tool wear process is similar to MRM as the tool and work-piece are considered as a set of electrodes in EDM Some useful applications exploiting both the advantages and disadvantages of electrode wear have been developed. Marafona etal introduced a wear inhibitor carbon layer on the electrode surface by adjusting the settings of the process parameters prior to normal EDM conditions**[58]**. Although the thickness of the carbon inhibitor layer made a significant improvement on the TWR, it had little effect on the MRR. Similar tool wear compensation strategies have also been applied to micro-EDM, which is commonly executed in thin layers using simple cylindrical or tubular electrodes. It was introduced that a uniform tool wear machining method compensating the longitudinal tool wear by applying an overlapping to to-and-fro machining motion**[59]**. Bleys etal initially evaluated the reduction of tool length based on pulse analysis and subsequently compensated the toolwear by controlling the machining downward feeding movement in real-time**[60]**. Dauw and Snoeys derived the measurement of tool wear from the study of pulse characteristics based on discharge voltage fall time. The different methods of simulating the EDM process also provide a good opportunity of understanding and compensating the tool wear**[61]**. Dauw (1988) developed a geometrical simulation of EDM illustrating the development of tool wear and part geometry.The simulation algorithm is largely based on MRR, TWR and spark gap. However, the simulation of discharge location and spark gap, which are dependent on the distribution of debris concentration, was reported to yield a more realistic representation of the sparking phenomenon**[62]**.Other methods include a reverse simulation of EDM obtaining the shape of the electrode based on the desired work-piece shape**[63]**.

VII. CONCLUSION

EDM has emerged as the most cost effective and high precision machining process in past years. The machining capacity to remove hard and difficult to machine parts has made EDM as one of the most important machining processes. The review of the research trends in EDM on die sinking, wire EDM, and their applications with metal matrix composites have been presented. In each topic, the development of the methods for the last 50 years is discussed.EDM has been employed in the tool, die and mold making industries. It also plays a significant role in medical, optical, jewellery, automotive and aeronautic industry. Such applications require machining of HSTR materials, which demand strong research and development and prompt EDM machine tool manufacturers to improve the machining characteristics. Hence, even after 65 years a continuous research is required to explore effective means of improving the performance of the EDM process.

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