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MODELING AND REVIEW ON ELECTROCHEMICAL DISCHARGE MACHINING

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Abstract: Electrochemical discharge machining (ECDM) process utilizes the spark discharge produced by gas film formation during electrolysis. In the conventional ECDM process, precise control of the spark generation is difficult because of the randomness of gas film formation which results in the significant deterioration of process qualities such as excessive overcut, poor machining accuracy and low machining repeatability. The undesirable overcut phenomenon strictly hinders the dimensional miniaturization of CDM process especially when the diameter of the applied tool is much smaller than 100 ptm. In this study a side insulated tool and dilute electrolyte concentration is proposed to reduce the undesirable overcut and thus, to improve the machining resolution of the ECDM process. Experiments are conducted with various machining parameters, such as spark ignition voltage, electrolyte concentration, and tool insulation. As a result, the feasibility of miniaturization in the ECDM process is phenomena. successfully improved by reducing the excessive overcut

Keywords: ECDM,Micro fabrication,Ansys,Modeling. Micro-Electro-Mechanical systems(MEMS)

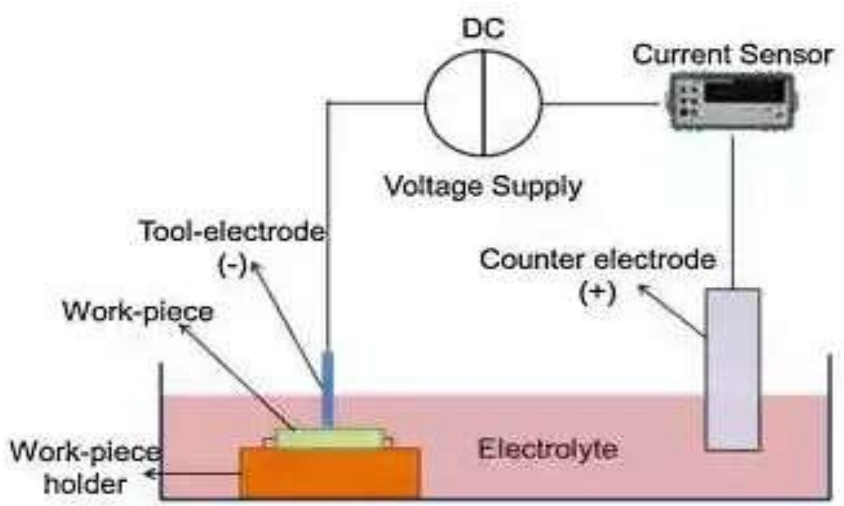
1. INTRODUCTION

In his quest for knowledge, man is utilizing the universe. Thiscall for state-of-the-art technologies to attain the maximum output in the form of speed, sense the weakest signal, actuate in the shortest time possible, etc. Thus, the knowledge touches upon all the branches of science, engineering and technology. Machining is the most basic need in the field of engineering. New methodologies and processes needed to be the new invention. Recent trends in production miniaturization of grown in automotive technology. Nano-machining and Micromachining have become the challenges of miniaturization of production. Since the very beginning of history, and even prehistory, humanity has invested a lot of effort to develop the skill of operation on every material. There is no need to present the fundamental importance of the capability of machining in any technology.New technology requires new inovation of a machine and machining skills. In the last century, there is need for using more and more specific materials (e.g., ceramic, composites or silicon) need high technology for operation. The last century works on the birth of micromachining, in particular, micromachining of silicon and glass. At present, the variety of micromachining techniques are available for silicon and glass. A similar situation lot of technology available for electrically conductive materials, where, in particular, electrochemical machining (ECM) and electrical discharge machining (EDM) are two powerful tools available for any type conductive materials. However, several electrically non-conductive materials have significant applications in the field of industry and daily life. Glass, composite materials, and silicon ar e the examples of the nonconductive material for the wide application. The technical requirements for using of glass as microsystems are growing day by day in the field of Medical devices and biocompatible. The importance of glass is also increasing in the field of micro-electromechanical Systems (MEMS). In particular, Pyrex glass is widely used because it can be bonded by anodic bonding (also called field-assisted thermal bonding or electrostatic bonding) to silicon. due to transparency, the glass used widely used in optical applications or in applications where optical visualization of a process is needed. Low thermal and electrical conductivity is some very interesting property of glass. It is amorphous and can, therefore, be chemically attacked in all directions. As glass is transparent, Some promising applications for glass in the MEMS field are micro-accelerometers, micro-reactors, micro-pumps, and medical devices (e.g., flow sensors or drug delivery devices).

A representative example in which glass-to-silicon bonding isused as bulk micro-machined accelerometers. In this case, Theglass serves many functions as

- Use as a seal and the required damping;
- It can use as capacitor when a metal plate is placed onit;

It is very difficult Micromachining on the electrically non-conductive brittle, hard glass. Diamond used for grinding, provide good geometrical accuracy.But by the diamond grinding surface finish is very poor and the machining efficiency is extremely low. Chemical etching is well-established, but its large taper angle and low aspect ratio are undesirable. By the laser, blasting makes very costly and tends to cause high thermal damage on the machined surface. Ultrasonic machining is very difficult to find the good surface finish. Recently, electrochemical discharge machining (ECDM) has been developed for machining non-conductive material such as glass, which has many applications in (MEMS) and microfluidic systems. ECDM has emerged as a new technology developed for micromachining of glass. In ECDM, as shown in Figure 1.1, tool electrode is the cathode, an auxiliary electrode is an anode. Both electrodes are immersed in the electrolyte solution (typically NaOH). Both electrodes are connected with DC power supply. When the applied voltage is increased to the critical value, Hydrogen bubbles are generated due to electrochemical reactions. Bubbles generation increase with increases voltage and concetration. When the bubbles become sufficiently dense enough by coalescing make a gas film on the tool electrode. The gas film work as resistance to break the circuit, the tendency to complete the circuit allows sparking by tool electrode. If the workpiece put close to the tool, (e.g., 25 μm for glass), the spark hit the workpiece material removal will occur by thermal damage. Although the exact material removal mechanism is not well understood, it is believed that both thermal erosion and chemical etching contribute to the material removal.



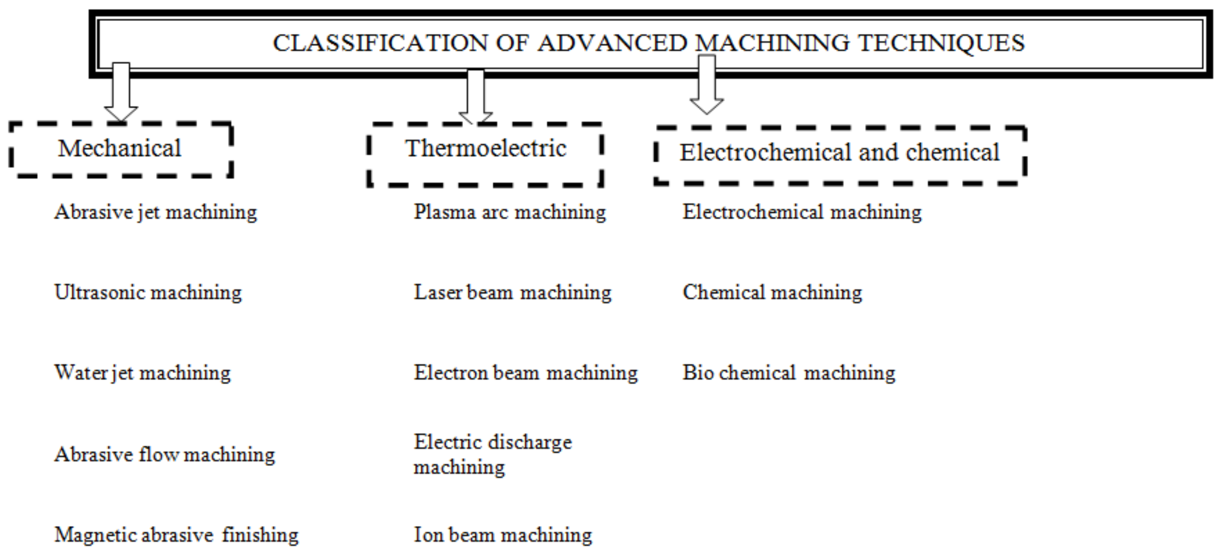
sFigure 1. Principle of electrochemical discharge machining

Drill by ECDM gravity feed(force between tool and workpiece) most common type of ECDM.

Wüthrich et al. (2006) studied that characterized the material removal rate(MRR) as a function of drilling depth for micro-hole gravity feed on drilling. Two drilling regimes were identified. During the first 200-250 μm of the hole depth, in the discharge regime, discharge effect dominates, and drilling speed depends on the number of discharges.Maillard et al. (2007) characterized the geometry and surface quality of micro-holes drilled in the glass. The authors revealed that with high voltage and high depth of cut lead to low geometric accuracy. Therefore, by ECDM deep hole drilling with high geometric accuracy is challenging. To improve the machining performance of ECDM, various methods have been presented. Tool rotation and tool vibration is shown to improve geometric accuracy and machining rate in ECDM. additional abrasive material also help to improve the machining rate. The objective of this study is to improve both the materialremoval rate and machining accuracy of ECDM by usingmicro-drilling tools.

2.Need for Advanced Machining Process

Technologically advanced industries like automobile, aeronautics, nuclear reactors, etc. have been demanding materials like high strength temperature resistant (HSTR) alloys having high "strength to weight" ratio. Researches in the area of materials science is developing materials which have higher strength, toughness, Hardness, and other diverse properties. This also require the development of improved cutting tool materials so that the productivity is not hampered. It is a well-established the fact that during conventional machining process an increase in the hardness of work material results in an increase the cost of cutting and decrease the speed. It is no longer possible to find tool materials which are sufficiently hard and strong to cut (at economic cutting speeds) materials like stainless steel, titanium, mnemonics and similar other high strength temperature resistant (HSTR) alloys, fiber- reinforced composite, satellites(cobalt-based alloys), ceramics and difficult to machine alloys. Production of complex shapes in such material by traditional methods is still more difficult. Other higher level requirement is better finished, low values of tolerances, higher production rates, complex shapes, automated data transmission, miniaturization, etc Making of holes (shallow entry angles, non-circular, microsized, large aspect ratio, a large no. of small holes in one work the piece, contoured holes, holes without burrs, etc) in difficult-to machine materials is another area where need appropriate processes are very much in demand. Aforesaid characteristics are commonly required in the products used in industries like aerospace, nuclear reactors, missiles, turbines, automobiles, etc.



Figuer 2; classifaction of machining process

3.Process for Advanced Machining

Advanced machining processes can be classified into three categories, i.e., by the conventional machine which is mechanical machining processes, Use of temperature that is thermoelectric machining processes and by the chemical reaction that is electrochemical or chemical machining processes. In all machining process, no one of these processes is the best of all machining situations and all materials. Some machine can be used for only electrically conductive materials while others can be used for electrically nonconductive materials. The hybrid machine can use for both conductive and nonconductive**.**

4.Electro Chemical Discharge Machining (ECDM)

Electrochemical spark machining is a very recent technique to Remove the material from both conductive and non-conductive material to obtain a desire dimensions required for engineering component by spark mechanism. From overcome of more tool wear rate we use the non-traditional machine, i.e., chemical machining (electrochemical machining), thermal machine (electro-discharge machining), mechanical machine (ultrasonic machining), etc. This is an immersed concept of hybrid machining (electrochemical spark machining) which is the combination of electrochemical machining(ECM) and electro-discharge machining (EDM) also known as spark assisted chemical engraving (SACE) by Fascio, electrochemical anode machining (ECAM) by Kubota, by Cook, spark assisted etching (SAE) by Daridon.

Requirement for machining

Anode - copper, aluminum, platinum, MMC, stainless steel, graphite, carbon rod

Cathode - tungsten carbide, steel, stainless steel, cobra rod, tungsten, graphite, copper, Pt plate, CuZu73 brass wire

$Cu \longrightarrow Cu^{2+} + 2e^-$

$2H_2O \longrightarrow O_2 + 4H^+ + 4e^-$

Electrochemical reaction at cathode

Due to following reaction hydrogen gas generated

$Cu^{2+} + 2e\ Cu \longrightarrow$

$2H^+ + 2e \longrightarrow H_2 + Na^+$

$2Na + 2H_2O \longrightarrow 2NaOH + H_2 + 2H_2O$

2e - $\longrightarrow$ H2+ 2OH-

The electrochemical discharge machining (ECDM) process is a combination of electrochemical machining (ECM) and electrical discharge machining (EDM) processes. This process has very good potential in the area of micromachining nonconductive hard and brittle materials such as ceramic, glass, quartz and Pyrex. ECDM process involves melting andchemical etching of the work piece due to high electricalenergy discharged on the tip of the electrode duringelectrolysis. The literature reveals that combined metal removalrate in ECDM can be 5 to 50 times over EDM and ECM withdecreased electrode tool wear 2–5. ECDM process requires two electrodes. One is the tool electrode, which is used to produce desired machined shape, and the other is the counter electrode or auxiliary electrode made as anode. The workpiece and counter electrode (anode) are immersed in an electrolyte solution (typically sodium hydroxide or potassium hydroxide). The tool electrode (cathode) is kept 2–3mm dipped in the electrolyte. Counter electrode or anode is a large size dummy electrode in general, which is kept at a distance of about 25– 50mm away from the tool electrode. Electrolysis starts when a voltage is supplied by a direct current (DC) power source between thetool electrode and counter electrode. A schematic of the process is shown in Figure 1.1. Surface area of the tool electrode submerged in the electrolyte is kept very small compared to counter electrode (anode). This results in high current density at the cathode. Rapid production of hydrogen gas bubbles takes place at the cathode due to ohmic heating of the electrolyte solution. Surrounding electrolyte insulatesthe immersed tool electrode (blanketing effect) by a gas film due tobubble coalescence as shown in figure 1.2. Gas film plays akey role in machining during ECDM

5.Literature Review

Indrajitbasak, Amitabhghosh et al. (1995): they studied that the when we apply DC voltage and current supplied the distribution of current in the tool (electrode) is not uniform because the disparity of the shape at the tool end face. The tip of the tool having less diameter compared to another end of the tool (electrode). Hence it is concluded that the formation of the spark will occur at the tip end.The flow of the current at the bottom face area of the tool is very small because of the blanketing by hydrogen gas, and it tends to zero. Due to complete circuit hydrogen gas generation start at the tooltip (cathode) in the form of the bubble. Bubbles size increases with the passage of the time when limited size is reached. All around the tool a blanket of gas is made which break the circuit, therefore increase the resistance at the tool –electrode interface due to the constriction effect increase ohmic heating of the electrolyte which is responsible for the generation of vapors bubbles. Hence the narration sites of the bubbles also increase. An isolated film generated between tool and electrolyte by the bubbles. At that time current drop to zero for very less time. This phenomenon is called switch off action of an electric circuit.

The emf can be shown as:

$$E = - LdI/dT$$

Whereas,

E= EMF (switching emf)

I= instantaneous current of the circuit

Since the value of dI/dT is very high spark takes place.

According to tohoogland and jannessen; to increase the current density more hydrogen bubbles generated.

Wenczel studied that bubbles are hemispherical and the growing size of bubbles diameter is not dependent on the current density. It only depends on buoyancy force and viscous properties of the electrolyte.The Liu yonghong et al. (1996): they gave their theory on gas-filled electro-discharge and electrochemical compound machining (GECM) process.According to him in conventional electrochemical spark process, the spark produced is very low efficiency because the electrochemical reactions occur in electrolyte solution consume more electrochemical energy and produce low spark erosion.

According to them the mechanism behind the spark formation is that when the tool side and end face are enveloped by gas by gas film system. When the high voltage is supplied to the tool and electrode (anode), electric field strength is generated between tool and solution due to which it reaches to the breakdown point of the gas film and electrical arc is produced. Due to this arc plasma temperature increases and due to viscosity and inertia of solution pressure rise also occurred. By this high temperature and pressure, the gas film around the tool expand quickly, and the gap between the solution and tool increase and the spark stops. After a large amount of gas is emigrant, then the electrolyte again goes towards the tool for the next arc.

Bhattacharya et al. (1998): in the ESDM process it has been found two types of reaction usually occur in the system.First electrochemical reaction at the tool surface whose examples are electrode dissolution plating, evolution, and oxidation. And the second chemical reaction in the electrolyte is the combination of chemical, precipitation reactions, and sludge.Electrochemical reactions act at the metal-electrolyte boundary layers and transfer of ions take place by Diffusion Transfer of ions in electric field convection DC power supply applies on the cathode and anode tool must be dipped 2-4mm in the upper surface of electrolyte initiate hydrogen gas and bubble formation start, as a result of heating of the electrolyte, small or few amount of electrolyte is evaporated and formed the steam. The gas bubbles are usually less ionic positively charged bubbles. Bubbles formation increases with the increase of the applied voltage at a critical voltage, sparking will be observed to take place between the gaps. Sparking is not between electrode and cathode, but it found the tool to the electrolyte across steam layers. Spark depends on the concentration, conductivity of electrolyte and tool geometry.VK Jain et al. (1999): proposed the Basak model of ECSM (Electro Chemical Spark machining) process based on 'Paschen curve' from the electric contact theory. First switching theory given by Basak was when the absolute pressure of the gas in the discharge tube increases for few millimeters of Hg then each gas evaporates as a bubble. Its breakdown due to the high electric field produced around the tool is the breakdown in the form of the arc. According to the valve, theory tool cannot be deeper more than 4-5mm.HuanShufou et al. (2011): they work on the gas film which is produced by the cathode. Due to gas film formation when the DC voltage is applied spark generation occurs. The increase and decrease thickness of gas film affect the spark intensity. So the gas film is the main factor for the spark intensity. This gas film is made of bubbles which are produced due to hydrogen evolution from the electrolyte solution. When the quantity of bubbles increased then the gas film thickness or a stable gas film is built due to which spark is occurred. As the spark intensity increase due to which heat of spark increase which accelerate the chemical reaction in an electrolyte and due to spark generated heat sublime the work piece slowly. And Huang increases bubbles by the high-speed rotation of tool or cathode. Min Seop Han et al. (2011): Han investigated that the tool surface texture can improve the spark intensity at lower voltage and low current. They work on the electric field intensity all around the tool. They explain this by a physical relation of electric field intensity with potential drop and thickness of the gas film. The relation is:

$$E= Vd/t$$

Here E = electric field intensity

Vd = potential drop

t = thickness of the gas film

As the tool tip is short and cylindrical than the gas film thickness around the cathode increases because of the tool tip cover less surface area as compared to the gas film so the thickness of gas film increases and potential drop decreases due to which electric field intensity increases and spark generated. At low voltage, the spark intensity is more due to the surface textured tool.Pankajkumargupta et al. (2015): they study that in electrochemical discharge mechanism is the combination of ECM and EDM .in this process the tool, workpiece, and the counter electrode are submerged into the solution (electrolyte). When DC voltage is supplied to the cathode tool and the counter electrode (anode) H2 (hydrogen gas) bubbles start forming at the tool face by the electrolysis process. These hydrogen bubbles envelope and coleuses tool surface area by the gas-filled which insulated the tool. The discharge takes place when the current density at the tool (cathode) faces high a critical value. Hence spark waves produced during the electrochemical discharge machining (EDM) phenomena. Ali Behroozfar et al. (2015): they studied that in ECDM process electrode (cathode as the tool) and anode (as the workpiece) are connected to the DC power supply and dipped in the electrolyte solution which is usually as the aqueous solution (NaOH). In such process, the cathode tool is dipped few millimeters in the electrolyte solution, and an anode electrode is bigger than the tool this is used as an anode (source not found). When the power applied to the electrode, electrolysis starts in the electrolyte because of the electrochemical reaction. Hydrogen bubbles at the cathode take place if the applied voltage increases more than a critical value (source not found). Bubbles get together and form an insulating film of hydrogen around the tool. At the particular voltage, the H2 (hydrogen gas) formed completely and caused the current drop or break the circuit (source not found). When the applied voltage is higher than the critical voltage, make the potential difference between the cathode (tool) and electrolyte as a result very intense electric field, and discharge takes place through the film.

6. Summary

Recent advancements in various aspects of electrochemical and electro-discharge machining that reflect the state of the art in these processes are presented in this paper. ECM and EDM technologies have been successfully adapted to produce macro, micro components with complex features and high aspect ratios for biomedical and other applications. These processes are also being attempted at the nano-scale.

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