Electrochemical Spark Machining Process for Non Conducting Materials: A Review

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Abstract: Advancements composite material need appropriate processes for machining of low machinability of materials with desired dimensional and geometric accuracy at a high rate of production and low cost. Electrochemical machining and electro discharge machining are the two advance machining processes which are used for machining of electrically conducting materials .The requirement of workpiece material to posses some minimum electrical conductivity is major limitation of ECM and EDM. To overcome these constraints hybrid machining process has been developed .The Electro chemical spark machining process (ECSM) process has been successfully applied for machining of non conducting materials such as soda line glass, borosilicate glass, quartz, fiber reinforced plastics and ceramics .ECSM (Electro chemical spark machining) is a hybrid technology that combines ECM and EDM. Electro chemical spark machining process (ECSM) is an un conventional machining process based on the electro chemical spark phenomena. In ECSM Material removal take place due to the combined effects of electrochemical reaction of electro chemical machining and electrical spark of electro discharge machining.

Keywords: non conducting material, ECSM, MRR, hybrid machining processes.

I. INTRODUCTION

Machining is process of controlled removal of material from workpiece to get desired dimensions required for engineering component. In traditional machining process tool material should be harder than work piece material. This limitation is overcome by many advanced manufacturing techniques, like Ultrasonic machining (USM), Electrochemical machining (ECM), Electro discharge machining (EDM), etc.

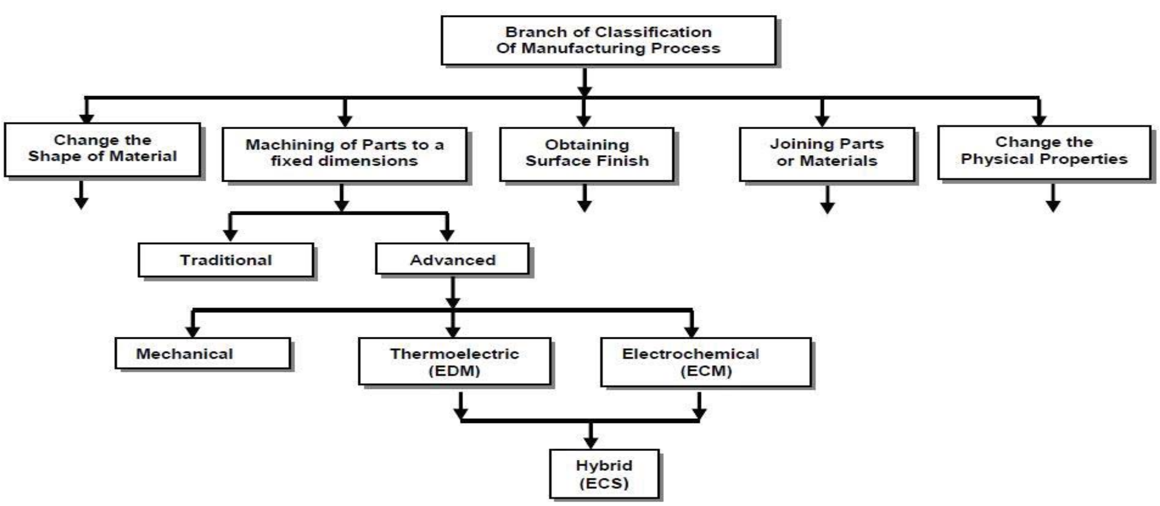

Figure 1: Classification Tree of manufacturing Process

To get advantage of more than one non-conventional machining there immerged concept of Hybrid machining. Electro chemical spark machining (ECSM) is also a hybrid machining process which is combination of Electrochemical machining (ECM) & Electro discharge machining (EDM) which is also known as, Electrochemical Engraving, Electrochemical Discharge Machining etc.

Spark and arc formation is not desirable in case of ECM as it damages workpiece and tool. But this phenomenon is useful for machining of non-conductive materials.

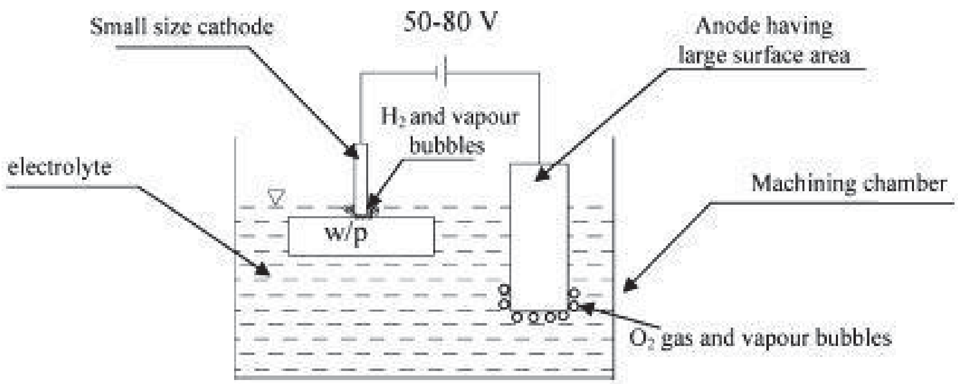

Figure 2: Schematic diagram of basic electrochemical cell in ECSM process.

II. MECHANISM OF GENERATION OF SPARK IN ELECTROLYTE

Electrochemical reaction at anode:-Generally copper is used as electrode & NaOH as electrolyte. Oxygen gas is generated at anode due to following electrochemical reaction.

$$\mathbf{Cu \rightarrow Cu^{2+} + 2e^{-}}$$

$$\mathbf{2H_2O \rightarrow O_2\uparrow + 4H^{+} + 4e^{-}}$$

Electrochemical reaction at cathode:-

Due to following reaction hydrogen gas is generated at cathode.

$$\mathbf{Cu^{2+} + 2e^{-} \rightarrow Cu}$$

$$\mathbf{2H^{+} + 2e^{-} \rightarrow H_2\uparrow \; Na^{+} + e^{-} \rightarrow Na}$$

$$\mathbf{2Na + 2H_2O \rightarrow 2NaOH + H_2\uparrow \; 2H_2O + 2e^{-} \rightarrow H_2\uparrow + 2OH^{-}}$$

In ECSM process generally two electrodes are largely different in size. Machining may takes place at cathode and anode. The electrode which is used as tool is called active electrode and which is small in size compared to another electrode, which is called as auxiliary electrode. Work piece is kept near to active electrode. Here, voltage applied is also large. Due to small shape at active electrode there is large current density so large amount of gas is generated there. This gas is nonconductive in nature. So this gas film acts as high resistance for electric current so ohmic heating also takes place & more number of gas bubbles are generated this gas is passivate active electrode. As applied voltage is above break down voltage of gas film there is occurrence of spark. Due to this spark gas layer break down takes place & again electrochemical reaction starts. This process continues. Generally power applied in pulsed form of micro second range. This process is shown by operation flow of ECSM.

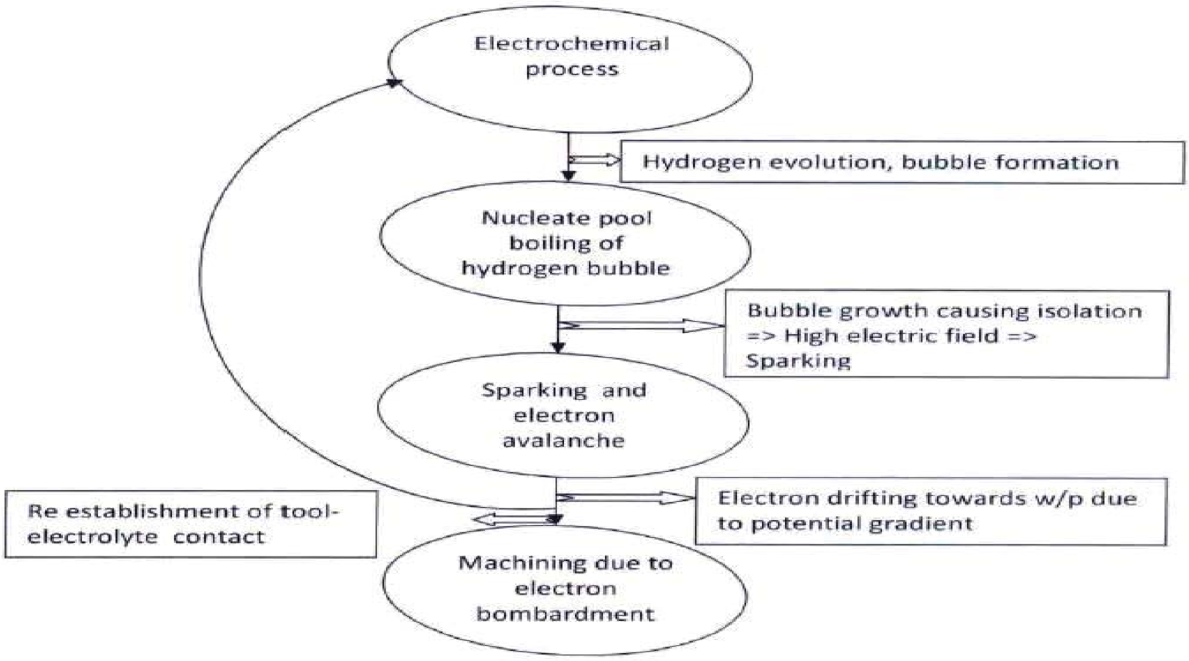

Figure 3: Operational flow of ECSM process showing intermediate processes

So, material removal takes place by combined effect of Melting, Vaporisation, Chemical reaction, Cavitation Erosion.

In ECSM we can perform machining at cathode as well as anode. When cathode is used as active electrode then it is called as ECSM direct polarity and when anode is used as tool then it is called as ECSM reversed polarity. In both case workpiece to be machined is kept near active electrode. Following table compare ECDP & ECRP.

	ECDP	ECRP
Cathode	Active Electrode (small in size)	Auxiliary Electrode (Large in size)
Anode	Auxiliary Electrode(large in size)	Active Electrode (small in size)

S. Tandon et al. (1990): developed ECSM set up for machining of Fibre reinforced plastics (FRP).Experimental set was developed and some empirical formula for evaluation of MRR, Tool wear rate, radial overcut.

Indrajit Basak et al. (1996) Explained Mechanism of spark generation during machining .Electrochemical spark phenomenon is used to machine non conducting materials is a very recent technique in the field of non-conventional machining.

Y.P. Singh et al. successfully developed the ECSM for machining of piezoelectric ceramics. In this paper travelling wire electro chemical; spark machining process set was designed and experimentation is performed. Conclusion of this experimentation is that MRR is increase with increase in supply voltage

Amitabha Ghosh et al. (1996) discussed Micro-welding Using electrochemical discharge phenomenon. Thios paper discuss the microwelding of thermocouples wire using electro discharge phemenon.

Amitabha Ghosh (1997) explained the principle and possibilities of electro chemical discharge machining.

Naveen Gautam et al. (1997) Performed the experiment on ECSD Process Using Various Tool Kinematics to enhance the process capabilities. Use of a rotational tool with controlled feed has been found to improve the process performance.

V. K. Jain et al. (1999) modeled the electrochemical discharge as a phenomenon similar to that which occurs in arc discharge valves. The spark energy and the approximate order of hydrogen gas bubble diameter are computed by the proposed valve theory. Material removal rate is evaluated by modeling the problem as a 3-D unsteady state heat conduction problem. The problem is solved by the finite element method to compute the temperature distribution which is post-processed for estimating material removal per spark, overcut obtained in the machined cavity, and attainable maximum penetration depth. The conclusion drawn is that the application of valve theory to the ECSM process seems to be realistic. Estimated material removal rate, overcut and maximum penetration depth show a good agreement with experimental findings.

B. Bhattacharya et al. (1999) experiment is performed to machine The highly purified non-conducting zirconium oxide is used as work piece material and aqueous KOH in stagnant condition as electrolyte with three different concentrations (i.e., 15 per cent, 25 per cent and 20 per cent). The applied voltage of pulsed d.c. power supply has three levels of 50V, 60V and 70V and the three different inter-electrode gap setting considered for the experiments are 20mm, 30mm and 40rnm respectively.

V. K. Jain et al. (2000) fabricated a set up of Electro-chemical Spark Trepanning machine which has been used to machining of Alumina and Quart .the Alumina and quartz (brittle, electrically non-conducting, and inert in nature) are popular materials in advanced engineering industries, but their shaping by the conventional machining processes is not possible; even ECM and EDM can't be employed to shape them because of their electrically non-conducting nature. However, an attempt has been made to find out the capabilities of a new process called electro-chemical spark machining (ECSM), in machining these electrically non-conducting, hard, brittle, and high temperature resistant materials. In this work, eccentrically rotating tools have been used. An experimental parametric study, it was found that beyond a certain value of electrolyte temperature, the ECSM process performance starts deteriorating. SEM photographs reveal that the combined action of melting and chemical etching seems to be the probable mechanism of material removal.

V.K. Jain at al. (2002) developed Electro-chemical spark machine for machining of alumina and glass. In this paper, abrasive particles are used on the drilling tool so the machine is known as electro chemical spark abrasive drilling (ECSAD) . Experiments have been conducted using abrasive cutting tools, with a view to enhance the capabilities of the process. Use of an abrasive cutting tool, when compared to a conventional cutting tool, has been found to improve the process performance, viz. enhanced material removal and increased machined depth. The work-piece materials used are alumina and borosilicate glass.

A. Kulkarni et al. Explained the discharge mechanism in electrochemical discharge machining. In this work they made an attempt to identify the underlying mechanism through experimental observations of time varying current in the circuit. They proposed the material removal and temperature rise mechanism.

W.Y. Peng et al. (2004). Performed experiment on Traveling wire electrochemical discharge machining (TW-ECDM) for machining of high strength and low thermal conducting material. The electrical–thermal etching effect and its feasibility are investigated. The energy release intensities and their physical phenomena under different sizes of discharge wires, power source modulations and methods of electrolyte supply are discussed. The pulsed dc power proves better spark stability and more spark energy release proportion than constant dc power. The input power is modulated to obtain the appropriate frequencies and duty factors for machining glass and quartz materials. The ion translation rate, the electrolyte immersing depth and the concentration of the alkali are found to be the dominant factors of bubbles reaction. Based on the SEM photographs of the work-piece surface, it is noted that the more purple the sparks from the mixed gases of hydrogen and vapor, the better the etching effect is. The V-shape defect occurring at the cut-in and cut-out can be significantly reduced by rotating the work-piece.During the wire EDM, five types of constraints on the MRR due to short circuit, wire breakage, machine slide speed limit, and spark on-time upper and lower limits are identified. An envelope of feasible EDM process parameters is generated for each work-material. Applications of such a process envelope to select process parameters for maximum MRR and for machining of micro features are discussed. Results of Scanning Electron Microscopy (SEM) analysis of surface integrity are presented.

K.L. Bhondwe et al. (2005) have modeled the MRR in ECSM using finite element methods, and prove it by experimentation. The increase in MRR is found to increase with increase in electrolyte concentration due to ECSM of soda lime glass work-piece material. Also, the change in the value of MRR for soda lime glass with concentration is found to be more than that of alumina. MRR is found to increase with increase in duty factor and energy partition for both soda lime glass and alumina work-piece material.

C.T. Yang et al. (2005) explained that the machining performance of wire electrochemical discharge machine is improved by adding SiC abrasive into electrolyte. This work aims to improve the over cut quality by adding SiC abrasive to the electrolyte. A mechanism that combines discharge, chemical etching and abrasive cutting is studied. The effects on expansion, roughness and material removal rate (MRR) are discussed.The experimental results reveal that adding abrasive reduces the slit expansion because it increases the critical voltage. The particles disrupt the bubble accumulation to form an isolating layer around the wire, increasing the critical voltage and reducing the discharge energy. The surface roughness is improved because the abrasive helps to refine the micro-cracks and melted zone that is formed by discharge heat erosion. Meanwhile, smaller grit produces lower roughness. The quality of the slit can be controlled; its expansion and roughness of the slit are 0.024mm and 0.84um Ra, respectively.

Min-Seop Han et al. (2007) concluded that surface integrity of workpiece material is improved when electro-chemical discharge machining process is performed using powder-mixed electrolyte. The fine graphite powder (which has good thermal and electrical conductivity) mixed with electrolyte has been applied to the ECDM process. Borosilicate glass, which is frequently used as a material for micro structures, was used as a work-piece. To investigate effectiveness of the proposed method experiments were conducted. The experiment results demonstrated that the breakdown voltage was reduced and the peak current during the process was decreased by ten percents. Discharging pattern was modified such that a single discharge pulse was branched into two or three. As a result, the surface quality was improved compared to that from the conventional process. Various experiment results of product quality with respect to powders volume ratio are also presented.

Sanjay K. Chak (2007) et.al. analyzed the trepanning of Al_2O_3 by electro chemical discharge machining process using abrasive electrode with pulsed DC supply . After experimentation the found that pulsed DC has reduced the tendency of cracking at high supply voltage compared to smooth DC and the machining ability of abrasive electrode was better than copper electrode as it would enhance the cutting ability due to the presence of abrasive grains during machining.

Xuan Doan Cao et.al.(2009) have investigated into micro structuring of glass with features less than 100µm by electrochemical discharge machining . In this paper the explained that to obtain stable gas film over the whole surface of the tool at low voltage a new mechanical contact detector based on load cell was used.

Cheng Kuang Yang et.al. analyzed the effect of surface roughness of tool electrode materials in ECDM performance [24]. In this work they compared the performance of different tool having different surface roughness value. They conclude that optimal voltage of different tool electrode can shed light on the machining performances.

Chih Ping Cheng et.a (2010). Have made a study of gas film quality in electrochemical discharge machining [25]. The gas film on the electrode surface is used as dielectric medium required for discharge generation. Quality of gas film is the dominant factor that determines the machining quality such as geometric accuracy, surface roughness and repeatability.

J. W. Liu et.al (2010). Explained the mechanism discharge phenomenon during the machining of metal matrix composites [26]. For this they performed a set of experiments to verify the model and the experimental results agreed well with the predicted values. The experiments results also showed that an increase in current, duty cycle pulse duration or electrolyte concentration would promote the occurrence of acting action in ECDM.

Cheng Kuang Yang (2011) et.al. have explain that by using spherical tool electrode the efficiency of ECDM enhanced [27]. Experimental results shows that curve surface of the spherical tool electrode reduces the contact area between the electrode and workpiece thus facilitating the flow of electrolyte to the electrode end and enables rapid formation of gas film, resulting in efficient micro hole drilling.

III. CONCLUSION

Electro-chemical spark machining process is a hybrid machining process which has been used specially for machining of non conducting material such as ceramics, composite materials. These materials have been developed to withstand at very high temperature, high stiffness but their machining is tough. To obtain high surface finish electrochemical machining process is mostly used.

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