CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURE SURVEY

Many researchers have done intensive work in the field of ECM leading to improvement in the performance.

Joao Cirilo da Silva Neto et al (2006) studied the effect of intervening variables such as feed rate, electrolyte, flow rate of the electrolyte and voltage on MRR, roughness and over-cut in SAE-XEV-F Valve-Steel. Over-cut is the material removed in excess in the lateral direction due to irregular anodic dissolution. Two electrolytic solutions NaCl and NaNO₃ were used of which NaNO₃ is reported to have produced better results of surface roughness.

Hocheng et al (2003) conducted some experiments for producing a micron size hole on the metal surface. A theoretical and computational model is presented to illustrate how the machined profile evolves as the time elapses. The results of the experiment show that the material removal increases with increasing electrical voltage, molar concentration of electrolyte, time of electrolysis and reduced initial gap.

Maehata et al (1987) explained the method of achieving mirror finish up to 0.01–0.02 µm in stainless and ordinary carbon steels within a short time and with high efficiency by using abrasive powder.
Ruszaj (1990) conducted experiments for improving the accuracy of electrochemical sinking. The results show that as the IEG decreases the machining accuracy increases.

Hewidy (2005) developed a new technique to utilize a simultaneously moving and rotating electrode to remove a specific amount of material from pre-machined holes and rods in hardened steel specimens.

The effect of valance electron on the MRR in aluminium has been investigated by Mukherjee (2008). Experimental results reveal that resistance of the electrolyte solution decreases sharply with increasing current densities. It appears that removal of a fraction of aluminium occurs in Al\(^+\) which subsequently gets converted into Al\(^{3+}\) through a series of chemical reactions.

Konig et al (1997) conducted experiments on ECM and reported that the major influencing variables are electrolyte type, tooling, control mechanism and mechanical parts that affect the process.

Yang (2006) studied the performance improvement in a wire cut electrochemical discharge machining by adding SiC abrasive to electrolyte. The experimental results reveal that the abrasive particles disrupt the bubble accumulation which forms 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. Meanwhile, smaller grit produces lower roughness.

Lohrengel (2005) investigated the quality of products machined by ECM using NaNO\(_3\) aqua solution. The formation of Fe\(^{3+}\) and Fe\(^{2+}\) were monitored by UV–VIS spectroscopy and enabled a quantitative product determination. A transition from predominant oxygen evolution to
predominant iron dissolution was found in the range from 5 to 30 A/cm². At current densities >35 A/cm² the oxygen evolution is formed to reduce some percent of the total current.

Rajurkar (1999b) discusses the developments in tool design, pulse current, micro-shaping, finishing, numerical control, environmental concerns, hybrid processes, and recent industrial applications.

Kozak (2000a) has developed the concepts of Computer-Aided Engineering system for solving the manufacturing problems of ECM such as: tool-electrode design, selection of machining parameters and their optimization.

A new simulation software for three dimensional ECM calculations has been developed by Leslie Bortels et al (2003). In this paper, the numerical model and solution method behind the software are presented and applied in the case of manufacturing of an automobile die and formation of a cavity.

Zhijian (2004) conducted a series of ECM experiments using a permanent magnet on the machine tool. It was proved that the extra energy provided by the magnetic field, decreases the critical voltage by exciting the particles to higher energy level. The electric flux helps to converge the magnetized ions.

The modeling of NC-electrochemical contour evolution machining using a rotary tool-cathode has been presented by Xu Jiawen et al (2005). This machining technology combines the advantages of ECM and numerical control (NC) techniques overcoming their own different disadvantages.
Some of the generic aspects of tool design for the electrochemical machining process were presented by Westley et al (2004). This work identified the insulation requirements and machined face considerations in order to design the electrode.

The results of theoretical and experimental investigations of the relationship between the characteristic shape dimensions imparted upon the anode-workpiece surface by the micro-features of the cathode-tool electrode under given machining conditions were presented by Kozak et al (2004). For improving micro-machining capabilities of ECM processes, the application of ultra-short pulse current and ultra-small gap size was recommended.

Lohrengel et al (2003) have conducted experiments on steel and other metals using neutral NaNO₃ solution by anodic dissolution at large current densities (about 100 A/cm²) and high electrolyte flow rates. A new flow-through concept was developed to realize flow and to suppress effects of side reactions like oxygen bubble formation and precipitation of products in order to improve the anodic solution process.

Piotr Domanowski and Kozak (2001) have presented the principles and mathematical modeling of a new method of shaping by electrochemical generating machining. The method presented was based on application of universal tool electrode such as flat electrode, cylindrical segments electrode, etc. and numerical controlled envelope movement of the tool. CAD software was developed for simulation of machining process and determined the kinematics of the tool electrode from the point of view of accuracy of required shape of workpiece.
Kozak et al (2001b) explained some of the fundamental processes, which occur during abrasive electrochemical machining and abrasive electrical discharge machining.

Rosenkranz et al (2005) have analyzed the different reaction products of ECM by quantitatively resolving for pulses by a combination of flow-through-micro cell with an UV–spectrometer and a pulse generator.

Clifton et al (2001) have explained the ECM characteristics of titanium aluminide by Chronoamperometric analysis. It is an electrochemical technique in which the potential of the working electrode is stepped, and the resulting current from faradic processes occurring at the electrode is monitored as a function of time. This form of attack can be correlated to differences in the valence and the overpotential. Overpotential is an electrochemical term which refers to the potential difference between theoretically determined and experimentally observed values. The term is directly related to a cell's voltage efficiency. These differences have been related to measured differences in the surface dissolution characteristics of the micro structural phases of this material. Surface hardness of the ECM TiAl has been shown to have decreased by 46% with respect to conventionally machined surfaces.

The knowledge about machining of electrically non-conductive materials like glass or some ceramics using electrochemical discharge phenomenon was reviewed by Wuthrich and Fascio (2005). Some main limiting factors were highlighted and possible solutions were presented.

Rajurkar et al (1998) studied on minimizing the material to be removed by predicting minimum machining allowance and improving the degree of localized dissolution. Experiments have been conducted to verify the prediction results on an industrial ECM system. The use of pulse current with passivating electrolyte has been found to mitigate the sludge generation and improve accuracy.
A numerical procedure for calculating the solution of the two-dimensional time-dependent electrochemical machining moving boundary problem was derived by Turgut Ozis (1991) using Boadway's transformation. The results were compared with those obtained earlier.

A new approach using electrochemical spark machining for cutting and drilling holes in composites has been proposed by Tandon et al (1990). The feasibility of using ECSM for machining FRP was first ascertained. Then a parametric study of the process was performed by planning the experiments using a ‘Design of Experiments’ concept as well as a ‘one variable at a time’ approach. They used Kevlar-fibre-epoxy and glass-fibre-epoxy composites as work materials, copper as the tool material and an aqueous solution of NaCl as electrolyte. It is concluded that ECSM is a viable solution for cutting FRP. However, for achieving the desired accuracy, surface finish and economics of the process, the machining parameters need to be optimized.

Simulation of ECM process with universal spherical electrodes has been performed by Kozak et al (2000b). The experimental investigations were carried out in order to evaluate the influence of working voltage, velocity of electrode, initial IEG size, tool-electrode cross feed and electrode radius on material removal rate and surface roughness. The neural network trained software is useful for surface prediction and optimization.

El-Dardery (1982) discussed the optimization of ECM process by using the variables such as current, voltage, electrode feed rate, electrolyte temperature and electrolyte flow rate.

Mohan sen et al (2007) attempted a hybrid neural network and genetic algorithm (NNGA) approach for the multi-response optimization of the electro jet drilling process. The simulated results were found to have a close correlation with the experimental data.
Investigation on the controlled ECM through response surface methodology has been presented by Bhattacharyya (1997). The investigation highlights the development of a comprehensive mathematical model for correlating the interactive and higher-order influences of various machining parameters on the dominant machining criteria, i.e., the material removal rate and the overcut phenomena, through response surface methodology.

Ebeid (2004) has studied the improvement of machining accuracy in ECM by hybridizing the process with low-frequency vibrations. The study highlights the development of mathematical models for correlating various machining parameters such as applied voltage, feed rate, back pressure and vibration amplitude on overcut and conicity.

Effects of electrolyte flow rate, electrolyte concentration, current density and voltage on the material removal and surface finish have been analyzed by Sorkhel et al (1994) using auto-feed system. The test results indicate clearly the optimal parametric combinations that are needed for enhanced metal removal and better surface finish. It is evident from the test results that the present study on ECM will be quite useful and a step forward for proceeding with further applied research for achieving effective utilization of ECM in practice, with better surface-quality characteristics so as to meet the needs of modern manufacturing industry.

Krishnaiah chetty and Radhakrishnan (1981) explained the effects of workpiece grain size and electrolyte velocity on the surface produced by ECM. The metallurgical characteristics of the work material play an important role in ECM. Surface profile analysis together with scanning electron microscope studies brought out the significant role played by the above two parameters in surface production, particularly on the short wavelength irregularities of the surface produced.
Rajurkar et al (1988b) have studied relationships for inter-electrode gap and surface characteristics in ECM. The effect of grain size on the machining gap, the ECM performance and tool design were discussed. The wavelength decomposition of surface profiles and current signals have been carried out with a view to develop a better understanding of surface generation and random occurrences of sparking in ECM respectively.

Masuzawa and Kimura (1991) have analyzed the surface finish of tungsten carbide alloy. A special design of the pulse train for alternate polarity ECM was proposed for realizing uniform design dissolution of tungsten carbide and for suppressing the dissolution of the tool electrode. The effectiveness was confirmed by applying the pulse on machined surface. A smooth surface without heat-affected layer or cracks was obtained. The experiments also led to hints for selecting the electrode material.

Neal (1986) has described the development of a microprocessor-based automatic restart control system capable of eliminating flaws caused by restarts during the electrochemical machining process. This makes a viable cost-effective technique for producing precision parts previously handled by conventional methods.

Hewidy et al (2007) have attempted to improve the ECM performance using low frequency vibration technique. The developed analytical model reveals that there could be a great complexity in the relationship between the tool amplitude and the equilibrium gap size, which could lead to tool damage, if the problem has not been carefully considered.

Rajurkar et al (1988a) have presented the effect of grain size on ECM performance. The reduction in the experimentally measured values of the final gap with the increase in work specimen grain size is used to develop
a correction factor. The prediction of the anode profile based on the correction factor and the improved COSθ method compares well with the anode cavity profile measured with a specially designed and built instrument.

Marius et al (2008) have developed 3D ECM simulation tool which is completely integrated in the computer-aided design (CAD) package ‘SolidWorks’. It helps to analyze the performance of ECM. This enables to perform the ECM configuration from scratch, or by reading in existing CAD files (STEP, AutoCAD, IGES, etc.).

Jain and Adhikary (2008) have analyzed the mechanism of material removal in electrochemical spark machining of quartz under different polarity conditions. Reverse polarity cuts quartz plate at a faster rate as compared to the direct polarity. But in reverse polarity overcut, tool wear and surface roughness are higher as compared to the direct polarity.

Mediliyegedara et al (2005) have discussed the new developments in process control for the hybrid electro chemical discharge process. The design stages and the implementation issues of a personal computer based real time controller for the ECDM process were discussed.

Electrochemical dissolution of hard metals such as TiC, TiN, pure Ti have been reported by Waither et al (2007) and found the nature of oxide film over the hard materials. The anodic surface oxide is not removed by cathodic current densities up to 30 A/cm².

Investigation has been made to evaluate the effect of the major controllable parameter ‘Voltage’ on the surface finish of P-20 grade cemented carbide by Suvadeep et al (2007). The effect of influencing parameters on
surface roughness using a non-dimensional parameter as ‘periodicity to randomness index’ was presented.

Park et al (2006) have discussed the effect of tool area on machining rate in micro ECM. As the tool area increases, the electrical double layer capacitance increases and subsequently the electrolyte resistance decreases. Also, it was observed from experimental results that the insulated tool improves the aspect ratio.

Pajak et al (2006) have conducted experiments on super alloys using laser assisted ECM and found that stray current effect on the machined surface is prevented. Laser beam with electrolyte jet enables an improvement of machining accuracy and productivity.

Chunjua et al (2006) have studied the importance of tool shape in assessing the performance in ECM. A turbine tool has been designed through the proposed approach using finite element method. The proposed approach is efficient and capable of designing 3D freeform surface tool from the scanned data of known workpiece without any iteration.

Wang Yihong (2002) has studied the electromagnetic theory and developed the mathematical model for ECM with fixed cathode. The mathematical model representing the actual machining process was given based on this new idea, and its numerical analysis was carried out. Moreover, the experimental results obtained were verified.

Zinovi Brusilovski (2008) has studied the adjustment and re adjustment of ECM process parameters for improving the performance. On the basis of experimental studies, the effect of primary control parameters such as operating voltage, electrolyte pressure, relative pulse duration, etc. on
IEG size has been revealed, and the task of electromechanical machine adjustment and readjustment has been developed taking into account the influence of disturbing factors and dimension scatter range in a batch of components.

Bhattacharyya et al (2005) have presented the effect of various electrochemical micromachining parameters like voltage, electrolyte concentration, pulse period and frequency on material removal rate, accuracy and surface finish in microscopic domain. It is found that machining at 3V, 55 Hz frequency and 20 g/l electrolyte concentration can enhance the accuracy with highest possible amount of material removal.

Zhu and Xu (2002) attempted to improve the accuracy of ECM using dual pole tool. The proposed tool brings down the current density at the side gap area of the machined surface and hence, reduces the stray metal removal. The results revealed that machining accuracy and the process capability were significantly improved.

Ramezanali et al (2008) have explained the polishing of gun barrel chamber by ECM. The results show that dimensional accuracy of the workpiece repeatability process in this polishing method is noticeable.

Mileham et al (1986) have made an attempt to find reasons that why macro defects were produced on electrochemically machined surfaces and how they can be avoided in practice to give integral surfaces. The integral electrochemically machined surfaces produced have been characterized in terms of $R_a$, skewness and kurtosis for a range of steels. The tests were carried out in a linear flow cell using a 10 % NaCl in water electrolyte. It has been found that changes in cutting conditions, particularly electrolyte flow velocity
and current density, produce significant variations in surface parameter values.

Shi Hyoung Ryu (2008) has attempted to develop safe and eco-friendly ECM by using citric acid electrolyte. He studied the effect of citric acid on stainless steel machining by ECM. The characteristics of ECM were studied through citric acid concentration, feed speed and electrical conditions.

The anodic metal dissolution of the alloyed carbon steel 100Cr6 was investigated by Haisch et al (2001) in NaCl and NaNO₃ electrolytes. In flow channel experiments, high current densities up to 70 A/cm² and turbulent electrolyte flow velocities were applied. Insoluble carbide particles cause an apparent current efficiency >100% in NaCl and >67% in NaNO₃. These particles were enriched at the surface in NaCl solution and detected by ex situ scanning electron microscopy and energy dispersive X-ray experiments. Qualitative metal dissolution models on the basis of the experimental results were proposed for the metal dissolution processes in the NaCl and NaNO₃ electrolytes.

Ahmet Hascalik and Ulas Caydas (2007) have studied the improvability of surface integrity in terms of machining voltage, electrolyte flow rate and table feed rate parameters of abrasive mixed electrochemical grinding and electric discharge machining in Ti6Al4V alloy. Scanning electron microscopy, X-ray diffraction, energy dispersive spectrograph and surface roughness measurement were performed to study the surface characteristics of the machined samples. Experimental results indicate that the abrasive mixed electrochemical grinding process effectively improves the surface roughness and eliminates the electric discharge machining damages completely by setting suitable grinding parameters.
Hewidy et al (2001) proposed the tool orbital motion as a new technique to enhance the ECM accuracy and to eliminate the presence of the spikes. A theoretical model has been derived to predict the shape of the frontal zone, the effective machining time and the effective feed rate.

Rajurkar et al (1999a) conducted experiments using eccentric orbital electrode and the results reveal that the surface roughness improves significantly.

A new modulated reverse electric field (MREF) ECM polishing process was developed by Sun et al (2001) for hard passive alloys surface finishing. An important parameter, MREF-ECM electric field waveform was investigated to optimize the ECM polishing process for IN718.

Ebeid and Abdel Mahboud (1988) have presented a comparative study, between rotating and non-rotating electrodes for the enlargement of conventionally pre-drilled holes. The comparison covered the rate of metal removal, dimensional accuracy, surface finish and power consumption. The beneficial advantages of using high rotational speeds on component accuracy are verified. The results emphasize that each process has its own particular characterization, appropriate field of application and tooling system.

Kozak et al (1991) investigated the effect of rotating tool in ECM and developed the mathematical model. This simulation allowed the user to choose a maximum practical tool feed rate with the inputs of gap size, pressure and temperature.

Zawistowski (1990) proposed a new system of electrochemical form machining using universal rotating tools for improving the electrolyte distribution over the workpiece.
So far, no research work has explored the effect of electrolyte jet pattern on ECM objectives; namely MRR and surface roughness. Positive results obtained through rotating tools and improved electrolyte distribution gives stimulus to further investigate their effect in ECM.

2.2 RESEARCH OBJECTIVE

- The objective of this research is to find ways for improving the performance of ECM.

- To analyze the effect of electrolyte jet patterns with non-rotating and rotating conditions of tool on the selected objectives namely; maximum MRR and minimum surface roughness.

- To enhance the performance of ECM using,
  - Straight jet in circular pattern
  - Inclined jet in circular pattern
  - Straight jet in spiral pattern
  - Inclined jet in spiral pattern
  - Inclined jet in square pattern and to analyze their effects on the selected objectives.

- To investigate the performance consistency of the electrolyte jet patterns using three different grades of materials namely,
  - Commercially available High Carbon High Chromium (HCHC) die steel with a hardness of 63 HRC
  - AISI 202 Austenitic stainless steel with poor machinability
  - AISI 1035 Medium carbon steel
➢ To analyze the effects of influencing parameters on the objectives using ANalysis of VAriance (ANOVA).

➢ Study the effects of influencing parameters such as tool feed rate, applied voltage, electrolyte discharge rate and rotary speed of the tool on the MRR and surface roughness.

➢ Optimization of influencing parameters using Response Surface Methodology (RSM) and to develop the mathematical models for maximum MRR and minimum surface roughness.