Study of Electro Chemical Machining Etching Effect on Surface Roughness and Variation with Chemical Etching Process

J.Kumar, S.Mandal and N. Mahato
Department of Mechanical Engineering
Brainware Group of Institutions-SDET, Kolkata - 700 124, INDIA

Abstract

This project has been made in an attempt to study the electro chemical etching & polishing in some alloys to obtain high surface finish. Electro chemical machining (ECM) is a non-conventional machining process based on the principle of electrolysis and hence it can be called as the reverse process of electroplating or anodizing. The removal of material from a substrate by chemical reaction or by ion bombardment is referred to as an etch process. In this dissertation an experiment is done on the mild steel plate, cast iron plate and aluminum plate. On which electrochemical etching and polishing is done and shows there effect on surface roughness and texture on variation of time, flow rate and current density. The results have been shown in great details in the result and discussion sections.

Keywords: Electro chemical machining, electro chemical etching, chemical etching, surface roughness, surface texture Words.

1. INTRODUCTION

ECM is one of advanced machining technologies and has been applied in highly specialized fields, such as aerospace, aeronautics, defense and medical industries. In recent years, ECM is used in other industries such as automobile and turbo-machinery because of its various advantages. Some genuine characteristics like negligible tool wear, high precision machining in difficult to cut materials, lower thermal and mechanical stress on work piece etc. makes ECM advantageous over other non-conventional machining processes. Still there are some challenges in ECM like generation of hydrogen bubbles and its effect on Material Removal Rate (MRR), complexity of tool geometry and its effect on various process parameters, prediction of electrolyte flow pattern and its impact etc. which have been investigated by various researchers. In case of complicated shapes of work-piece it's very difficult to know the machining variables distribution within the inter electrode gap (IEG). By studying the flow pattern of electrolyte, we can predict the machining variable distribution accurately and thus can avoid the passivation which is the major problem in ECM in complicated shape cases. Again, two phase effect (hydrogen bubble generation) has a major role on the machining variables as well as on the material removal rate and surface roughness. The flowing electrolyte collects the evolving hydrogen gas generated at the cathode. The presence of hydrogen in the electrolyte reduces the specific conductivity of the solution and thereby the overall effect is a reduced MRR and a deterioration of the surface finish. So we need to study the sources, effects and pattern of hydrogen bubble generation and its impact on various critical parameters and overall machining performance. So, these are the motivating factors behind this project work.

The process of metal removal by electro chemical dissolution was known as long back as 1780 AD but it is only over the last couple of decades that this method has been used to advantage. It is also known as contact less electrochemical forming process. The note worthy feature of electrolysis is that electrical energy is used to produce a chemical reaction, therefore, the machining process based on this principle is known as Electrochemical machining(ECM). This process works on the principle of Faraday's laws of electrolysis.

ECM can be thought of a controlled anodic dissolution at atomic level of the work piece that is electrically conductive by a shaped tool due to flow of high current at relatively low potential difference through an electrolyte which is quite often water based neutral salt solution.

In ECM, Electrolyte is so chosen that there is no plating on tool and shape of tool remains unchanged. If the close gap (0.1 to 0.2mm) is maintained between tool and work, the machined surface takes the replica of tool shape.

Similar to EDM, the work piece hardness is not a factor, making ECM suitable for machining difficult to machine materials. Difficult shapes can be made by this process on materials regardless of their hardness. A schematic representation of ECM process is shown in Figure 1.2 The ECM tool is positioned very close to the work piece and a low voltage, high amperage DC current is passed between the work piece and electrode. Some of the shapes made by ECM process.

2. CHEMISTRY OF PROCESS

During ECM, there will be reactions occurring at the electrodes i.e. at the anode or work piece and at the cathode or the tool along with within the electrolyte.

Let us take an example of machining of low carbon steel which is primarily a ferrous alloy mainly containing iron. For electrochemical machining of steel, generally a neutral salt solution of sodium chloride (NaCl) is taken as the electrolyte. The electrolyte and water undergoes ionic dissociation as shown below as potential difference is applied

$NaCl \leftrightarrow Na^+ + Cl^-$ $H_2O \leftrightarrow H^+ + OH^-$

As the potential difference is applied between the work piece (anode) and the tool (cathode), the positive ions move towards the tool and negative ions move towards the work piece.

Thus the hydrogen ions will take away electrons from the cathode (tool) and from hydrogen gas as:

$2H^+ + 2e- = H_2 \uparrow$ at cathode

Similarly, the iron atoms will come out of the anode (work piece) as:

$Fe = Fe^{++} + 2e-$

Within the electrolyte iron ions would combine with chloride ions to form iron chloride and similarly sodium ions would combine with hydroxyl ions to form sodium hydroxide

$Na^+ + OH^- = NaOH$

In practice $FeCl_2$

ISBN: 978-93-80689-28-9

And Fe $(OH)_2$ Would form and get precipitated in the form of sludge. In this manner it can be noted that the work piece gets gradually machined and gets precipitated as the sludge. Moreover, there is not coating on the tool, only hydrogen gas evolves at the tool or cathode. Fig. 1.1 depicts the electro-chemical reactions schematically. As the material removal takes place due to atomic level dissociation, the machined surface is of excellent surface finish and stress free.

Cathode Reaction

$Na^+ + e^- = Na$; $Na + H_2O = Na(OH) + H^+$;$2H^+ + 2e- = H_2 \uparrow$

It shows that there is no deposition on tool but only gas is formed, whereas, in cathode in machining an iron.

Anode Reaction

Iron (Fe) $\leftrightarrow$ $Fe^{++} + 2e^-$;$Fe^{++} + 2cl^-$ $\leftrightarrow$ $Fecl_2$;$Fe^{++} + 2(OH)^-$ $\leftrightarrow$ Fe (OH) $Fecl_2 + 2(OH)^-$ $\leftrightarrow$ $Fe(OH)_2 + 2cl^-$

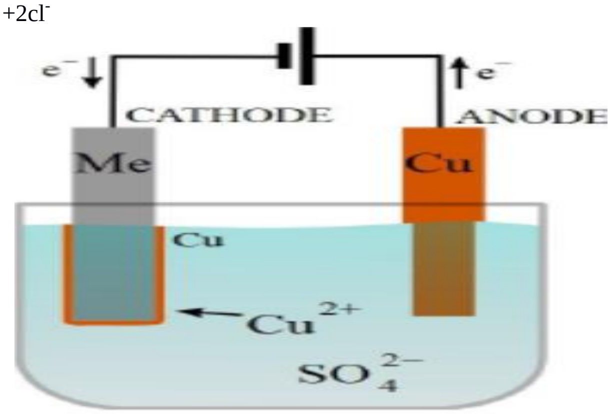

Fig. 1.1 An Electrolyte Cell

It shows that metal (work piece) i.e. Fe goes into solution and hence machined to produce reaction products as iron chloride and iron-hydroxide as a precipitate. Interesting part is that the removal is an atom by atom, resulting in higher surface finish with stress and crack free surface, and independent of the hardness of work material

Smaller the inter electrode gap (IEG) the gap, greater will be the current flow because resistance decreases and higher will be rate of metal removal from the anode. Higher current density, in small spacing (usually about 0.5mm or less) , promotes rapid generation of reaction products.

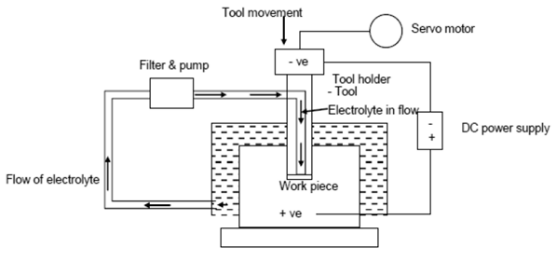

Fig. 1.2 Electrochemical Machining Set-ups

3. ELECTROCHEMICAL ETCHING

There are two types of etching mechanisms: Physical etching (or sputter etch, and relies on momentum transfer from particles hitting and eroding the surface) and wet/dry chemical etching (where reaction products formed are either soluble in the etch solution or volatile at low pressures). The removal of material from a substrate by chemical reaction or by ion bombardment is referred to as an etch process. The material that is not masked is removed resulting in patterned regions. The rate of material removal is known as etch rate (ER) and is the thickness removed per unit time (nm/min). For high production throughput, we need etch rates above 50 nm/min. Depending on the etch process and material, the etching can occur in both horizontal and vertical directions. The anisotropy of an etch process is given by A = 1 –(ERL/ERV) ERL= lateral etch rate, ERV= vertical etch rate. Chemical etch processes are typically isotropic; ERL= ERV and A = 0. The effect of an isotropic etch rate is to create undercuts below the mask. An ideal etch process would transfer the pattern on the mask to the underlying film with zero lateral etch, creating a vertical profile.

4. CHEMICAL ETCHING PROCESSES

Etching is traditionally the process of using strong acid or mordant to cut into the unprotected parts of a metal surface to create a design in intaglio (incised) in the metal. In modern manufacturing, other chemicals may be used on other types of material.

In traditional pure etching, a metal (usually copper, zinc or steel) plate is covered with a waxy ground which is resistant to acid. The artist then scratches off the ground with a pointed etching needle where he or she wants a line to appear in the finished piece, so exposing the bare metal. The chopped, a tool with a slanted oval section, is also used for "swelling" lines.

5. EXPERIMENTAL METHOD

5.1 Specifications

Supply voltage :230V AC 50HZ
Power consumption:280W maximum
Polishing voltage :0-60V
Polishing current :0-3 Amp
Polishing timer :0-90 sec.
Etching voltage :0-18V(to be set with sample)
Etching current H range :0-750 milliamps
Etching current L range :5-30 milliamps
Etching timer :0-90 sec
Pump speed control :Electronic
Dimensions
Length(L) :430 mm
Height(H):330 mm
Width(W) :235 mm
Weight :11 kg (Approx.) Without electrolyte

5.2 Etching Reagent For Micro-Examination

(a)Concentrated Nitric Acid 2c.c.

Absolute Methyl Alcohol 98c.c.

(b)Saturated solution of picric acid in alcohol.

Time required in each case is 10 – 30 seconds. Solution(a) is used preferably for grain boundary etching and solution (b) for pearlite. A 10% solution by hydrochloric acid in alcohol is useful for etching hardened steels.

5.3 Surface Roughness Testing by Taly-surf after electrochemical etching process

Cast Iron

Parameters	Symbols	Unit	Level1	Level2	Level3
Voltage	V	Volt	18	12	6
Time	T	Time	5	10	15
Average Roughness	Ra	µm	0.780	1.225	1.465

Table No-I

Mild Steel

Parameters	Symbols	Unit	Level1	Level2	Level3
Voltage	V	Volt	18	12	6
Time	T	Sec	5	10	15
Average Roughness	Ra	µm	0.995	1.098	1.390

Table No-II

Aluminium

Parameters	Symbols	Unit	Level1	Level2	Level3
Voltage	V	Volt	18	12	6
Time	T	Sec	5	10	15
Average Roughness	Ra	µm	1.566	2.033	2.418

Table No-III

5.4 Surface Roughness Testing by Taly-surf after chemical etching process:

Cast Iron

Parameters	Symbols	Unit	Level1	Level2	Level3
Time	T	Sec	5	10	15
Average Roughness	Ra	µm	1.234	1.358	1.462

Table No-IV

Mild Steel

Parameters	Symbols	Unit	Level1	Level2	Level3
Time	T	Sec	5	10	15
Average Roughness	Ra	µm	0.356	0.59	0.852

Table No-V

Aluminium

Parameters	Symbols	Unit	Level1	Level2	Level3
Time	T	Sec	5	10	15
Average Roughness	Ra	µm	0.391	0.318	0.311

Table No-VI

6. EXPERIMENTAL RESULT

6.1 Plot between time and average surface roughness for electrochemical etching process:

The plot shown in fig A of between time and average surface Roughness for electrochemical etching process shows that variation of Ra with time of electro chemical etching process. From the study of graph we found that the material having the more ductility is higher surface roughness with increase in time of etching process. The study of aluminium shows that have the higher surface roughness then mild steel and cast iron.

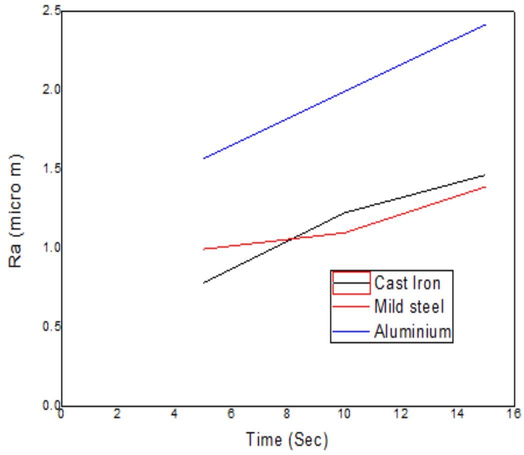

Fig A Plot between Time and Average Surface Roughness for electrochemical etching process

6.2 Plot between time and average surface roughness for chemical etching process:

The Plot shown in fig B between time and average surface roughness for chemical etching process shows that variation of Ra with time of chemical etching process. From the study of graph we found that the material having the more ductility is lower surface roughness with increase in time of etching process. The study of aluminum shows that have the lower surface roughness then mild steel and cast iron.

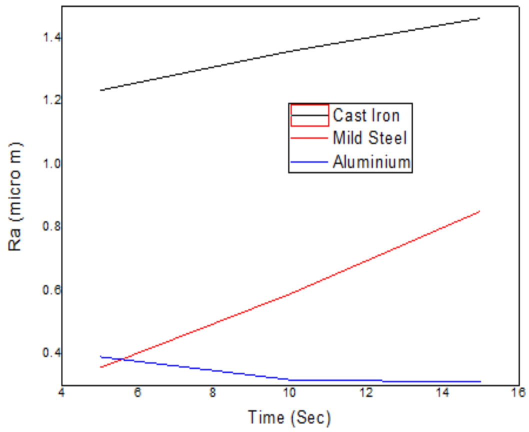

Fig B Plot between time and average surface roughness for chemical etching process

6.3 Plot between voltage and average roughness for electrochemical etching process:

The Plot shown in fig C of between Voltage and average surface roughness for electrochemical etching process shows that variation of Ra with voltage of electrochemical etching process. From the study of graph we found that the material having the more ductility is higher surface roughness with increasing in voltage of etching process. The study of aluminium shows that have higher surface roughness then mild steel and cast iron.

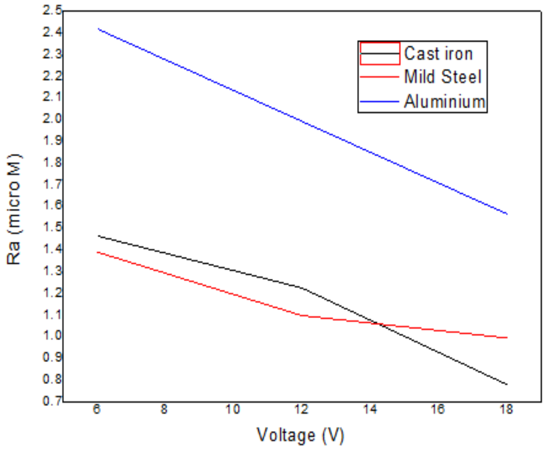

Fig C plot between voltage and average roughness for electrochemical etching process

7. CONCLUSIONS

The extensive use of experimental studies preliminary to the design & construction of new material or structural elements & the use of testing procedures for control of established processes of manufacture & construction are significant & well recognized features of ours.

The plot shown in fig A of between time and average surface Roughness for electrochemical etching process shows that variation of Ra with time of electro chemical etching process. From the study of graph we found that the material having the more ductility is higher surface roughness with increase in time of etching process. The study of aluminum shows that have the higher surface roughness then mild steel and cast iron.

The Plot shown in fig B of between time and average surface roughness for chemical etching process shows that variation of Ra with time of chemical etching process. From the study of graph we found that the material having the more ductility is lower surface roughness with increase in time of etching process. The study of aluminum shows that have the lower surface roughness then mild steel and cast iron.

The Plot shown in fig C of between Voltage and average surface roughness for electrochemical etching process shows that variation of Ra with voltage of electrochemical etching process. From the study of graph we found that the material having the more ductility is higher surface roughness with increasing in voltage of etching process. The study of aluminum shows that have higher surface roughness then mild steel and cast iron.

References

[1] N.N.Li, “High Throughput Fabrication of Titanium Nanopillars by Maskless Plasma Etching” National Key laboratory on Micro/Nano Fabrication Technology, Institute of Micro Electronics, Peking University, China.

[2] D. Berestovskyi, “Electrochemical Polishing of Micro Component, ICOMN” March 25-28 ,(2013) ,University of Victoria.

[3] Marek St. Węglowski, “Electrolytic Etching in Welding Metallographic”(2013) Testing of Materials Weldability & Welded Construction Dept. PhD.

[4] Niveen J. Abdalkdir, “Study of electrochemical Polishing Applications in Some Alloy to Obtain High Surface Finish (2012)”University of Technology/ Materials Engineering.

[5] Niveen J. Abdalkadir, “Study of Electrochemical Polishing Applications in Some Alloy For High Surface Finish” July 3-6 ,(2012),University of Technology,Baghbad,Iraq**.**

[6] J.Electrochem, “Electrochemical Studies of Interation of Qurcetin With DNA” College of Chemistry & Chemical Engineering, Northwest Normal University, Lanzhou 730070 ,Gansu, China,(2006)**.**

[7] F. HAIRER, “Etching Techniques for the Microstructrual Characterization of Complez Phase Steels by Light Microscopy” Technical University of Munich Christion Doppler Laboratory of Material Mechanics of High performance Alloys, Chair of Materials Science And Mechanics of Materials, VOEST ALPINE Straβe 3,postfach, Linz A-4031, Austria(2004**).**

[8] Inger Ekvall, “Preparation and Characterization of Electrochemically Etched W tips for STM” Meas,science. Technol. 10 **(**1999**)** 11-18,Physics and Engineering physics Chalmers University of technology, E-412 96 Goteborg,Sweden, Printed in UK.

[9] Inger Ekvall, “Preparation and Characterization of Electrochemically Etched W tips for STM” Recived 4th septmber 1998, in final from 29th October 1998, accept for publication 3rd November 1998, Uppsala University, The Angstrom Laboratory, Box 534, SE-75I 2I Uppsala,Sweden.

[10] Khadry A. Galil, “Acid Etching Patterns on Buccal Surfaces of Permanent” PEDIATRIC DENTISTRY/Copyright 1979 by the American academy of Pedodontics/vol.1 no.4/printed in USA.

[11] M.Inman, “Electropolishing and Throughmask ElectroEtching on Nitinol Stents and other Materials in an Aqueous Electrolight” Faraday Technology Clayton, Ohio, USA.

[12] Avinash P. Nayaket, “Logeeswaran VJ$^{¥}$ and M Saif Islam” University of California,davis.California.

[13] V.Palmieri, “Fundamental of Electrochemistry-The Electrolytic Polishing of Metals:Application to copper and niobium” Istituto Nazionale di Fisica Nuceare, Laboratory Nazinali di Legnaro**.**