Electro Chemical Machining of Micropin Tool Using Ultrasonic Vibration Polishing

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Abstract*- Micro Electric chemical Machining (MECM) is one of the most efficiently employed non-traditional machining process for cutting hard-to-cut materials & to cut geometrically complex shapes that are difficult to machine by conventional machines. In the present paper reviews is conducted of experimental investigations carried out to study the effect of Electric chemical Machining parameters on material removal rate (MRR), electrode wear (EWR), surface roughness (Ra) and diameteral overcut n corrosion resistant stainless steels. The non-contact machining technique has been continuously evolving from a mere tool and die making process to a microscale application machining alternative attracting a significant amount of research nterests and Electrochemical machining offers several special advantages including higher machining rate, better precision and control, and a wider range of materials that can be machined.*

Keywords- MECM, MRR, Ra EWR

I. INTRODUCTION

Material removal techniques have a pivotal role to play in component fabrication. In recentyears many high strength alloys such as copper beryllium and titanium alloys were produced that are extremely difficult to machine using the traditional processes. These alloys were developed for a variety of industries ranging from aerospace to medical engineering. Machining these alloys with conventional tools results in subsurface damage of the workpiece and in tool damage. The tool size and geometry limit the final component shape that can be machined. Another problem with these tools is that they tend to leave burrs on the machined surface. These burrs are undesirable in many applications. For example, in the medical industry the presence of even very small burrs will damage living tissues where these machined parts are used as implants. In electronic devices where a number of components are in close contact, the burrs may lead to short circuits. In mechanical components burrs may result in a misfit. Electrochemical machining (ECM) can machine these alloys. Devices are becoming smaller as time progresses but their features are increasing at the same time. Machining materials on micro and sub-micro scale is considered a key technology for miniaturizing mechanical parts and complete machines. Micro manufacturing techniques find application in various industries such as electro-communications, semi-conductors and ultra-precision machinery. A suitable manufacturing technique for mass production of these micro scale components needs to be established. The current techniques used for machining these components are mainly the dry vacuum process and wet chemical etching (Datta 1998).

These techniques come under the non-conventional machining processes category. The major difference between conventional and non-conventional machining processes is that conventional processes use a sharp tool for material removal by physical means where as the non-conventional techniques remove material by utilizing chemical, thermal, or electrical energy or a combination of these energies (Groover 2006). These processes suffer from several inherent problems. Dry-etching techniques require high cost equipment and do not offer good selectivity in material removal. The chemicals used in wet etching processes are commonly toxic and extreme care has to be taken to dispose of them. These techniques can precisely perform 2D machining at the micro level, that is, they can machine thin films extremely well. However, they are unable to produce 3D components and components with high aspect ratio. Most of these techniques were developed for the electronics industry specifically silicon. Silicon does not find applications in fields other than the electronics industry because it is toxic. High exposure to silicon dust causes chronic respiratory problems (Lenntech 1998). These techniques also suffer from limitations such as restricted materials choice, inability to produce complex profiles, and huge investment for facilities and equipment (Rajurkar et al. 2006). Electrochemical machining is a non-conventional process that found wide-spread.

1.1Application and advantages:

1. It can machine difficult to cut materials, generate complex contours, produce a stress free surface, and have no tool wear.
2. It has been used in various industries at macro level.
3. Electro-chemical machining can be used effectively for micro machining components by suitable tool design and process control.
4. Electrochemical machining uses direct current with the current applied continuously.

This project proposes a new approach of μECM, which uses pulsed current and a feedback loop. The advantages of pulsed current are that it aids in the effective removal of metal ions between anode and cathode and it offers good control of the etched surface. The feedback loop is to be designed in such a way that the system detects variations in the current in machining zone and automatically compensates for them.

II. OBJECTIVES AND SCOPE

The main objectives of this study would be:

1. Develop model for material removal rate (MRR) for μECM.
2. Design a system for micro machining.
3. Compare open loop/closed loop results.
4. Predict the system behavior and compare with measured data.

III. REVIEW OF LITERATURE

Corbett et al. and Tenigyohi [10, 11] suggested that electrochemical machining (ECM) has seen a resurgence of industrial interest in the last decade due to its various advantages, such as no tool wear, stress free and smooth surfaces of machined product and ability to machine complex shapes in electrically conductive materials, regardless of their physical and chemical properties.

Dutta, et al. and Osenbruggen et al. [12, 13] This article propose that electrochemical micromachining (EMM) appears to be a promising micromachining technique, since in many areas of application, it offers several special advantages that include higher machining rate, better precision and control, and a wider range of material that can be machined. A better understanding of the high rate anodic dissolution is urgently required for EMM to become a widely employed manufacturing process in the micro manufacturing domain.

Dolbier et al. [14] suggested about the insulation of the electrode that a few methods can coat a micro electrode with a very thin insulation layer. Glass coating is widely used to insulate the side faces of electrodes, but the coating layer is too thick to use for micro electrodes. To reduce coating thickness, additional operation of etching is required. A polymer like parylene has been used for conformal coatings in a wide variety of applications. Insulated tool electrodes have many advantages.

They can yield maximum machining rate because the rising time of the double layer potential is minimized. The machining rate of the insulated tool electrode is much higher than that of the uninsulated tool electrode. The machining depth can be increased because there is no size effect according to the machining depth, as shown in Fig. 2.1

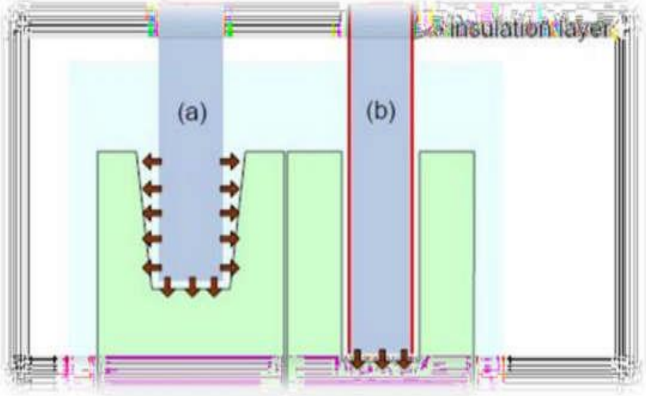

Fig 3.1(a) Schematic diagram of side effect (a) uninsulated tool, (b) insulated tool.

Bhattacharyya et al. [15] defined that for a better understanding of high rate anodic dissolution processes is urgently required for electrochemical micromachining (EMM) to become a widely employed manufacturing process in the electronic and precision manufacturing industries particularly in the micro manufacturing domain. A successful attempt has been made to develop an EMM setup for carrying out in depth independent research for achieving satisfactory control of electrochemical machining process parameters to meet the micromachining requirements. The developed EMM setup mainly consists of various subcomponents and systems, e.g., mechanical machining unit, micro tooling system, electrical power and controlling system and controlled electrolyte flow system, etc. All these system components are integrated in such a way that the developed EMM system setup will be capable of performing basic and fundamental research in the area of EMM fulfilling the requirements of micromachining objectives.

Datta et al. [22] have used various compositions of phosphoric acid and sulphuric acid with butyl alcohol, isopropyl alcohol, glycerol as well as chromic ac id for finishing of high-speed print bands. They observed that a mixture of butyl and isopropyl alcohols does not improve the surface finish, while the mixture made with chromic acid causes localized attack and produces highly rough surface. On the other hand, an electrolyte with glycerol gives good surface finish because it influences the physical properties of the electrolyte. It also affects the transport properties of the diffusing species, thereby creating favourable conditions for finishing. Apart from these, it lowers the operating current density.

P. S. Pa, [23] suggested that the basic purpose of providing the ultrasonic vibration is to cause effective discharge of electrolyte and by-products in ECF/ECP. Experimental results show that ultrasonic vibrations can give 21 44% improvement in surface finish, depending upon the process variants and conditions used. The use of ultrasonic energy began in 1927 to produce holes in a glass bar. Later on, its application was extended to welding, metallurgy and cleaning processes. Likewise, it has been utilized in electrochemical finishing processes to enhance surface finish.

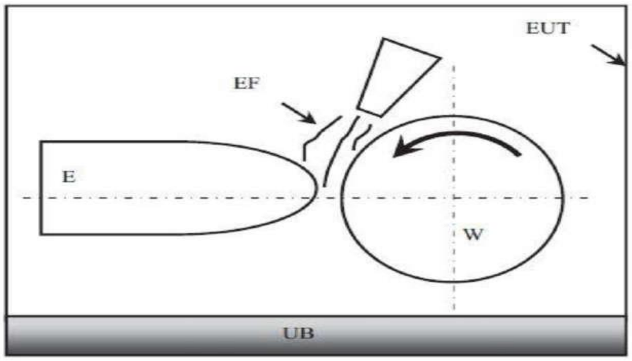

Fig 3.1(b) Ultrasonic electrochemical finishing process

Where E, electrode (cathode); EF, electrolyte flow; W, work (anode); EUT, electrolytic and ultrasonic tank; UB, ultrasonic base, Feed of cathode perpendicular to page in and out.

3.2 Electrochemical Polishing Process:

Mahdavinejad and Hatami [24]have reported that the electro-chemical machining appears to be inner surface polishing of complex parts with high precision can be easily done by electrochemical polishing method. In this research, cartridge house inner surface electrochemical polishing of a gun pipe, with numerous serial surface angles, is analyzed. So that, according to the various set ups, the optimized polishing parameters are obtained. The comparison between electrochemical polishing and conventional methods from this point of view, shows good advantages of this method, so that, themachining time is more than 30 times less and with very high-surface quality. Besides, the dimensional accuracy of the work piece repeatability process in this polishing method is noticeable.

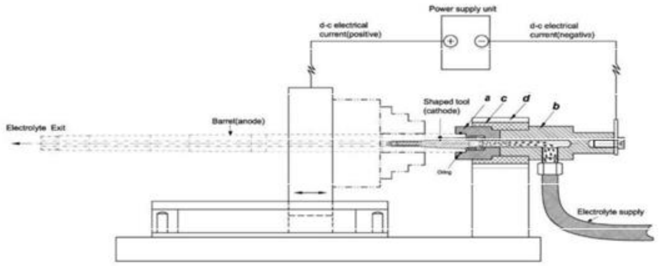

Fig 3.2(a) Schematic View of Fixture and the circulation of electrolyte

3.4 Electrochemical Turning Process:

Taweel and Gauda (28) integrated the electrochemical turning (ECT) process and magnetic abrasive finishing (MAF) to form a combined process that restores the material removal rate (MRR) and declines surface roughness (SR). A comprehensive mathematical models based on response surface methodology (RSM) for relating the cooperating and higher-order influences of major machining parameters, i.e. magnetic flux density, applied voltage, tool feed rate and work piece rotational speed on MRR and SR of 6061 Al/Al2O3 (10% wt) composite. Supporting ECT with MAF is a creative and encouraging process that leads to an increase machining efficiency and resultant surface quality significantly, as compared to that achieved with the traditional ECT of some 147% and 33%, respectively. P. S. Pa (29) studied a newly designed finishing process employing an effective electrode and a grinding tool to perform the continuous electrochemical finishing and grinding processes followed by turning process. The electrode was tested with both continuous and pulsed direct current. A higher workpiece rotational speed produced a improved finish. Changing the electrode design from a semicircle to a segment form with a small end radius caused the electrolytic products and heat to dissipate more rapidly and provided the best finishing. Pulsed direct current finishing was to some extent better than using continuous direct current finishing. However, the use of pulsed current would increase machining time and cost. The continuous processes of electrochemical finishing and grinding succeeding turning by the design finishing necessitate a lesser time to produce smooth and bright work piece surface ith an effective electrode and a grinding tool provide the optimum value for higher current density, and it provides larger discharge space, thereby producing a smoother surface. The use of a higher electrolytic flow rate and a high work piece rotational speed creates a better finish.

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3.6 Electrochemical Grinding Process:

Maksoud and Brooks [30] have informed that the research investigates the process of electrochemical grinding (ECG) used to machine metal-bonded diamond composite wheels. These wheels have been used as form tools to grind ceramics. The wheels must be machined to form and to tight tolerances, in good time. The best methods of the metal-bonded types are those with mild steel and bronze bonds. To machine these wheels using ECG, direct nickel-plated diamond composite form tools has been used. In order to achieve the vital tight tolerances and minimum production time, the method has to be optimized. The optimization standard was based on the tolerances of the machined form, on the surface topography of both the metal bond wheel segments (as the work piece) and the plated form tool and correspondingly on the grinding time observed. Operational constraints such as feed rate, electrolyte flow and current density, were investigated. The optimum operating conditions were evaluated. A comparison with conventional grinding methods was made also.

Curtis et al. [31] discussed about design and manufacture concerns are detailed for a hybrid electrochemical grinding unit modified from a vertical machining centre using a 40000 rpm spindle and 500A DC generator. Consequently, experimental work is accessible on the impact of tool bond systems, super abrasive grit type and electrical parameters when simultaneous ECM/grinding Udimet 720 using 10 15 mm diameter plain points. Single layer electroplated CBN tools produced G-ratios and maximum normal cutting forces of 450 and 45 N, respectively, compared to 128 and 557 N for equivalent diamond wheels. Data on work piece unevenness and overcut are also offered as are initial results for a fir tree shaped tool.

3.7 Electrochemical machining of Ti alloys:

Clifton et al. [36] displays characteristics of low density, high stiffness, good creep resistance and high strength at extensive range of temperatures make titanium aluminide a potentially significant material in respect of weight savings in high performance components working at high temperatures. Some work has previously been conceded to inspect properties of the machining of this alloy using mechanical stock removal techniques such as turning. Such approaches are found to have confines in terms of surface integrity blemishes and the formation of surface hardened layer. In this paper the ECM features of titanium aluminide are examined. Conditions under which reproducible ECM is viable for this material has been established and parameterised in terms of machining constraints generated from chronoamperometric analyses for both chloride and per chlorate electrolyte systems.

IV. OUTCOME OF LITERATURE REVIEW

The literature survey helped to successfully design, construct and conduct the experimentation of this research work. Some of the major ideas learnt from the literature survey are listed below.

1.Theexperimental setup is designed based on the various requirements stated by above cited literature.
2. The specific studies of each process parameters made by various authors on for MRR and Dimensional deviation are helpful to understand the behaviour of each parameter.

3. Necessary ideas were obtained for making a suitable tool for the current study.

4. Clear outline about Taguchi methodology, and various other optimization techniques were learnt.

5. It is learnt that experimental investigation considering 5 most 37influencing process parameters viz. Electrolyte Concentration, Machining Voltage, Machining Current, Duty Cycle, and Frequency on MRR is yet to be conducted.

6. It is understood that further research is to be conducted on Nickel and its alloys for
maximum MRR.

7. Further study is needed in the area of Dimensional deviation. Hence, it is inferred that more in depth research involving maximum number of process parameters are to be conducted to achieve maximum MRR with less dimensional deviation for Nickel and its alloys.

V. WORKING PRINCIPLE

Electrochemical machining removes material from an electrically conductive work piece. The basis of this process is electrolysis, which is governed by the laws established by Faraday.

5.1 Electrolysis

Electrolysis is the chemical reaction that occurs when an electric current is passed between two conductors dipped in a liquid solution. The completeness of this electric circuit is found by attaching an ammeter to the system and ammeter displays a reading. The liquid solution conducts electricity because otherwise the circuit would be incomplete.

5.2 Electrochemical Machining

Electrochemical machining is a material removal process similar to electro polishing. In this process the workpiece to be machined is made the anode and the tool is made the cathode of an electrolytic cell with a salt solution being used as an electrolyte. The tool is normally made of copper, brass, or stainless steel.

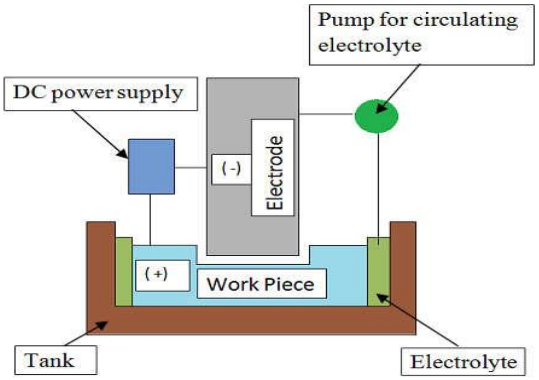

Fig 5.2(a) Schematic of ECM

5.3 Deburring

Burrs are undesirable in any machined work piece but are at the same time inevitable. Deburring the machined components manually is a time consuming process and also not effective (McGeough 2005). Electrochemical machining with its inherent advantages is a suitable choice for deburring. A flat faced tool is used to remove the surface asperities on the work piece.

VI. THEORY OF ELECTROCHEMICAL MACHINING

6.1 Material Removal Rate

The amount of material removed is determined by Faraday's first law which states that the mass of the substance removed at an electrode is proportional to the quantity of current passed to that electrode. So,

$V=Cit$

where,

V = volume of metal removed (mm3)
C = electrochemical constant (mm3/amp-s)
I = current (amps)
t = time (sec)

6.2 Rate of Machining

The rate at which different metals can be machined depends on the amount of current passed and the duration for which it is passed. This is an indirect way of expressing the statement that the rate at which the material is removed is dependent on the rate of reaction according to Faraday’s law

6.3 Geometry, Condition, and Accuracy of Machined Surface

The geometry, condition, and accuracy of the machined surface depended on the electrolyte salt type and concentration, machining gap, pulse power supply setting, flow velocity, and flow profile (Stofesky 2006). µECM is capable of producing surfaces free of any metallurgical alterations. It was observed that nickel based, cobalt based , and stainless steel alloys produce smoother surface (0.13 to 0.38 µm Ra) compared to surface finish obtained on iron based alloys and steel (0.63 to 1.52 µm Ra). Surface finish was governed by the mass transport at the anode. A better surface finish was obtained on work pieces with fine grained structure (Rajurkar et al. 2006). An electro polished surface was obtained when dissolution occurred at or beyond the limiting current.

VII. RESULTS AND DISCUSSION

7.1 Analysis Of Holes Drilled In Copper

Figure shows some kind of layer formed on the surface of CA-173 after machining. It was suspected that this layer impeded machining and further tests were performed to obtain the composition of the layer.

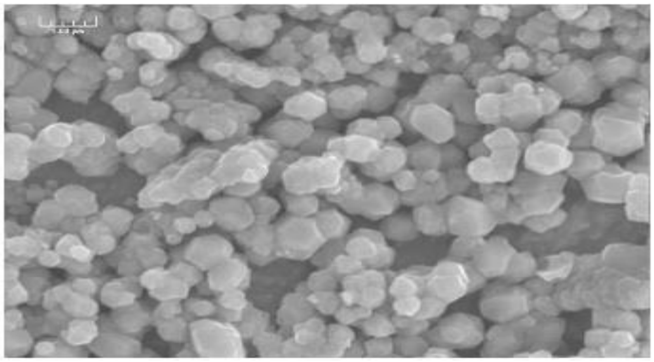

Fig 7.1(a) Surface of CA-173 workpiece after µECM at 0.5 KHz and 16 Vpp

Figure shows images of stainless steel electrode that was used to machine 8 holes in CA- 173.There was a clear indication of deposition on the electrode. (b) shows the bottom of the electrode whereas (c) shows a side view of the electrode.

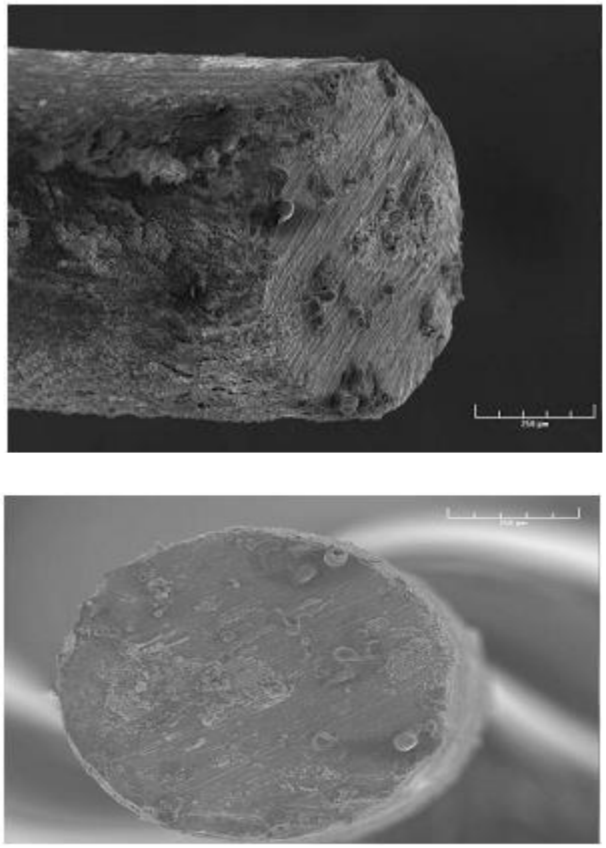

fig 7.1 (b)Fig 7.1(c)
Stainless steel electrode after machining CA-173 workpiece at 0.5 KHz and 16Vpp

VIII. ULTRASONIC VIBRATION POLISHING RESULTS

µECM was successfully applied to deburr micro components. Figure showsthe component with burrs along the edges.

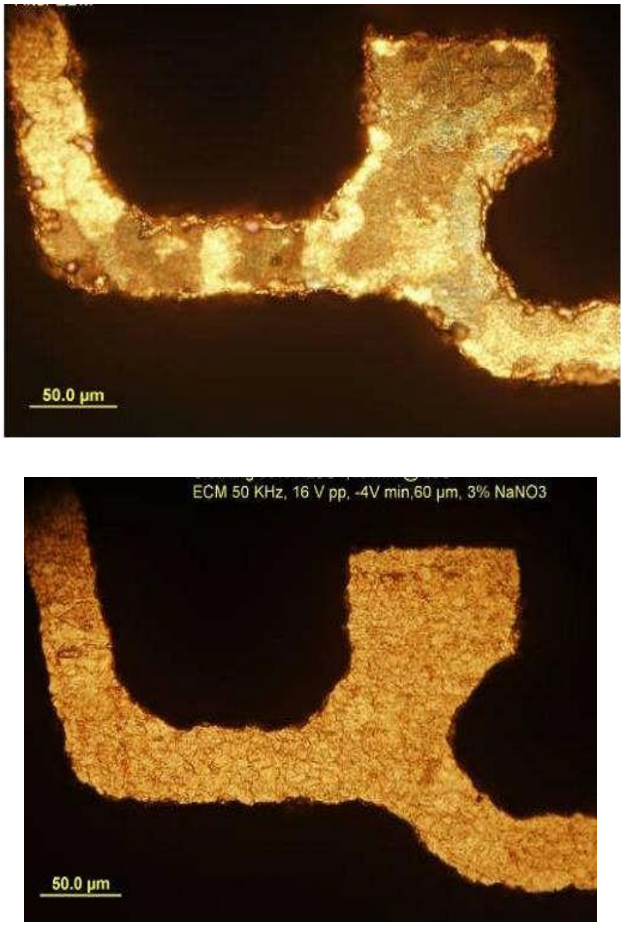

Fig 8(a)Micro electronic component with burrs Fig (b)Component Ultrasonic polishing withµECM along edges at 50 KHz ,16 Vpp and ø500 µm tool

8.1.1 Parameters for deburring calculated by model table (i)

Number of pulses	684000
Speed (µm/s)	137
Time (s)	14.62

The plot obtained from EDS on a stainless steel electrode that was used to drill 8 holes in CA-173 is shown in Figure . The composition of each element and their source are tabulated in Table.

8.1.1 Results of quantitative analysis on stainless steel electrodetable(ii)

Element	Composition (%)	Source
Nickel (Ni)	41.04	Coating on electrode
Iron (Fe)	19.07	Tool material
Copper (Cu)	18.79	Workpiece material
Oxygen (O)	9.42	Oxidation
Sodium (Na)	6.9	Oxidation

It was observed that there was a high concentration of nickel at the electrode tip. It wasfound that the commercially available stainless steel pins that were being used as electrodes had nickel coating on them which reacted with the copper and formed a layer of non conductive layer which impeded further machining. This was the reason that the current and voltage readings appeared constant but there was no machining take place. Figure shows image of a hole drilled on a 100 µm thick CA-173 sheet with a 500 µm diameter stainless steel electrode.

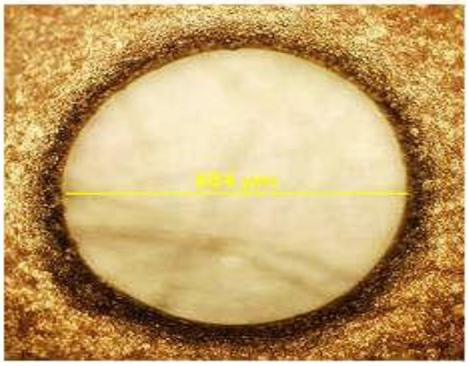

Fig 8.1(c) Hole drilled on 100 µm thick CA-173 sheet at 50 KHz and 16 Vpp

IX. ANALYSIS OF HOLES DRILLED IN STAINLESS STEEL

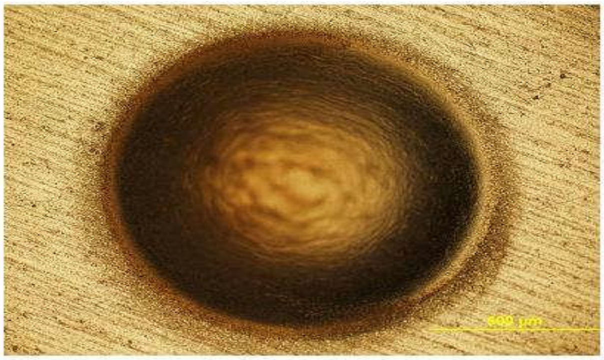

Fig.9.(a)Optical image of hole drilled on 500 µm thick SS-316L sheet at 0.5 KHz and 16 Vpp

Figure shows image of a hole drilled on 500 µm thick SS-316L sheet with a Ø660 µm SS- 316L electrode. It was reported by Viola Kirchner et al. (2001) that the addition of fluoride and chloride ions was crucial for micro machining of stainless steel. As a result of oxidation, passivation layer of iron, chromium and nickel were formed on the surface inhibiting further machining. The addition of the halide ions destabilized the oxide so that further machining could progress. The set of experiments were conducted without the addition of any acid due to the difficulties in handling them and in compliance with lab policies. Figure shows the top surface of a hole drilled in SS316L. The observation of grain structure indicated that electrochemical machining eroded grain boundaries due to high strain energy at grain boundaries.

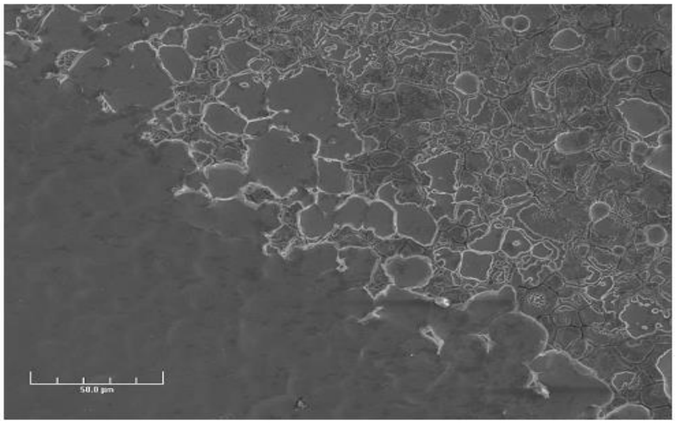

Fig 9 (b)

The picture showed differences in texture because in the region where there was electrolyte flow machining tool place and grain structure was visible. Figure shows image of a hole drilled on 500 µm thick SS-316L sheet. It was observed that the edges were smooth without any burrs emphasizing the fact that µECM produces workpieces without any burrs.

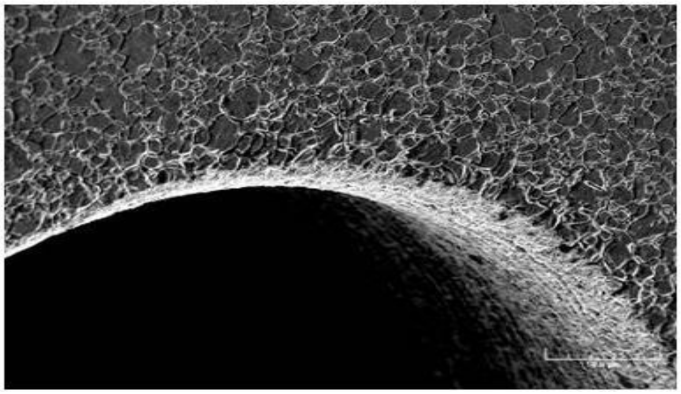

Fig 9(c) Hole drilled on 500 µm thick SS-316L sheet at 1 KHz and 16 Vpp

Ultrasonic Pulsating current has three parameters: pulse on time, pulse off time, and peak current density which can be varied independently to achieve desired machining rate. By suitable choice of the above parameters, variations of electrolyte conductivity in the machining region could be reduced and high, instantaneous mass transport achieved even at low electrolyte flow rates. The appropriate selection of length and duty of pulse was essential to obtain the best surface quality. Experiments performed to study the effect of variation in pulse on time and pulse off time on surface quality indicated thatshort pulse on time and high pulse off time yield improved surface with less pitting (Rajurkar et al. 1999). The experiments that were conducted maintained the same pulse on/off time while machining at low frequencies. The pulse off time was more than the pulse on time at high frequencies to enable the electrolyte to flush away the machining products which was in accordance with existing data. Figure shows plot of surface roughness versus pulse on and pulse off time.

X. CONCLUSIONS

A novel μECM with vibration polishing system was developed:

- Using high frequency pulses.
- A model was developed for material removal rate using pulsed current.
- The system was used to successfully form micro holes and for profile refinement.
- Experimental data on small drilled holes agreed with theoretical data within 10%.
- Micro burrs can be effectively removed by optimal μECM setup.

XI. FUTURE SCOPE

- Future work includes using pulsed laser to enhance the process. It is assumed that the pulsed laser would enhance the rate at which the reaction products are flushed out of the machining zone resulting in a higher material removal rate. The pulsed laser would heat up the machining zone locally increasing the rate of anodic dissolution.
- The model for material removal rate can include the effect of pulse OFF duration and flow rate to accurately predict the material removal rate.

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