

Mathematical modeling and hydrodynamics of Electrochemical deburring process

Satisha Prabhu^{1,3,4}, Dr Abhishek Kumar K^{2,3,4}

¹ Research Scholar, Department of Mechanical Engineering,

² Assistant Professor, Department of Industrial Engineering,

³ Pandit Deendayal Petroleum University, Gandhinagar-382007, India.

⁴ Email: satishaprabhu@gmail.com, abhishek.k@sot.pdpu.ac.in.

Abstract. The electrochemical deburring (ECD) is a variation of electrochemical machining is considered as one of the efficient methods for deburring of intersecting features and internal parts. Since manual deburring costs are comparatively high one can potentially use this method in both batch production and flow production. The other advantage of this process is that time of deburring as is on the order of seconds as compared to other methods. In this paper, the mathematical modeling of Electrochemical deburring is analysed from its deburring time and base metal removal point of view. Simultaneously material removal rate is affected by electrolyte temperature and bubble formation. The mathematical model and hydrodynamics of the process throw limelight upon optimum velocity calculations which can be theoretically determined. The analysis can be the powerful tool for prediction of the above-mentioned parameters by experimentation.

Keywords: Electrochemical deburring, Hydrodynamics, surface texture, electrolytic conductivity, specific resistivity, current density.

1. Introduction

There are various international and national standards as well as proprietary standards for describing burrs and evaluating the quality of component edges. For thousands of years there was no word for a 'burr' formed by machining, but Erasmus Darwin, the grandfather of Charles Darwin, a naturalist, and poet, appears to be the first person to mention "burr" in writing (1784) [5]. Burrs are those undesirable metal projections which accumulate on the edges of machined parts after metal cutting, grinding, shearing or most other cutting operations. Burrs are often termed as real productivity killers and the last thing which will be looked into by the engineers. As a result, the entire subject has been actively ignored. Burrs can be very painful, emotionally and physically. It has been found that the money and much time spent on scientifically investigating burr removal. In actual practice, a shop floor worker usually solves the burr problem – and this usually means manual deburring. As a result, many project budgets do not even include the cost of deburring. The absence of deburring strategies may result in a part that consumes more time and money to produce it. Generally, engineers feel that as tool technology improves, the whole burr problem will disappear. Since chip formation cannot be ruled out so as the burr formation. The Very high precision cutting tool will also produce burrs at the work piece edges. Various techniques were developed in recent past to remove burrs but the science of burr



removal is still a major issue that needs to be resolved. Techniques developed in the recent past include manual scraping, grinding, sanding them off, vibratory tumbling, high-temperature burning, dissolving them with acid and electrocuting in salt water. Despite these efforts, burr removal is still a challenging problem.

2. Overview of Electrochemical deburring

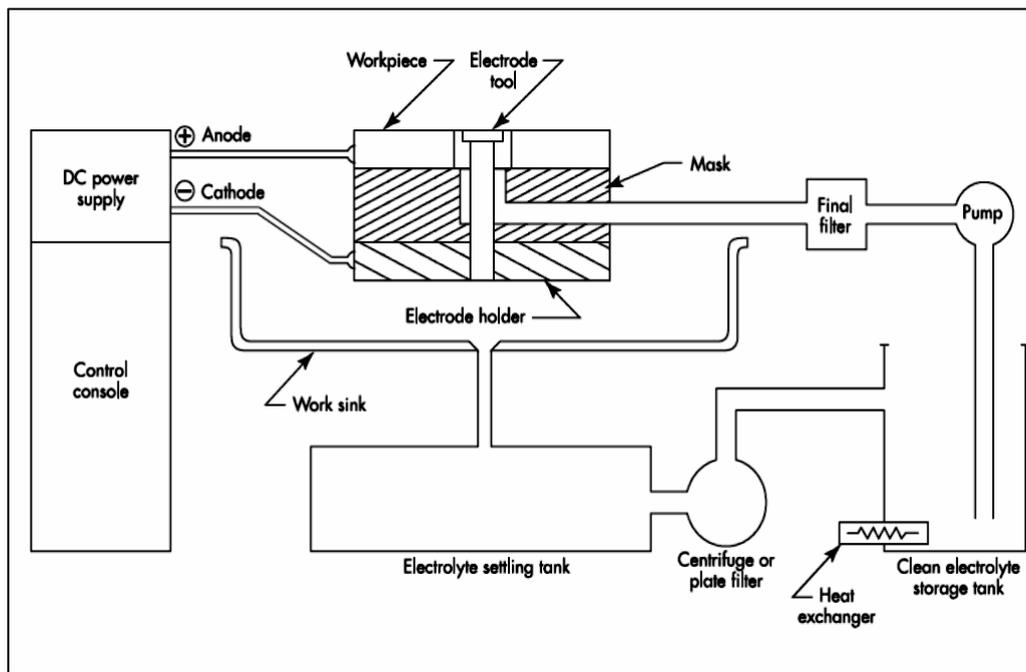


Figure 1. The line diagram of electrochemical deburring. (Source: Deburring and Edge finishing Handbook [11])

An Electrochemical machining process technology can be employed for deburring purpose due to various reasons. This process (ECD) is an advanced method of electrolytic dissolution which can be used for precision component parts. Its major attribute is that it does not require simple tooling or no tooling in some of the cases. Any component can be considered from its material of construction, form, dimensional accuracy, surface texture and heat treatment [03] and not from its surface integrity and edge quality. These aspects are important for performance and life of a product point of view. A component produced by a conventional method of machining is having burrs along its edges or intersecting surfaces. Burrs are unwanted and could lead to following drawbacks. It can cause injury, jamming of machinery, interference of mating parts, scoring of mating parts, minimize friction and wear, metal contamination, stress concentrations, plating build-up on edges and cut softer material parts etc. Hence deburring process attained considerable importance not only from the quality standard point of view but also from the cost of finishing. The deburring process can be manual, mechanical, abrasive, thermal, chemical and electrochemical. The mechanical and manual process can only minimize the burr and found unreliable. The abrasive deburring process proved to be having low metal removal rate, poor uniformity and tend to charge the work piece with grit. Thermal deburring can cause burning at elevated temperatures. In electrochemical type burrs are dissolved to obtain the finish. ECD works on the same principle as that of ECM. The tool may or may not be insulated since the machining is done only for few seconds.

The tooltip should overlap the area to be deburred by 1.5 to 2.0mm. ECD is suitable for parts with intersecting holes, inaccessible areas and where other methods proved to be ineffective. The magnitude of the voltage and current density are comparatively lower than ECM. The current magnitude and duration of flow for a particular component is determined by trial. The sodium chloride (NaCl) and sodium nitrate (NaNO₃) electrolytes are commonly used.

Common metals can be deburred electrolytically are given : Aluminum – Processing time: normal, Copper – Process speed: slow, Gold – Process speed: very slow, Invar – Process speed: normal, Iron, malleable, cast – Process speed: fast, Kovar - Process speed: normal, Lead – Process speed: very slow, Magnesium – Process speed: fast, Platinum – Process speed: won't process, Silver – Process speed: fast, Sintered iron – Process speed: very fast, Steel, carbon – Process speed: slow, Steel, cast – Process speed: fast, Steel, stainless – Process speed: normal, Titanium – Process speed: very fast or won't process, Tungsten – Process speed: very slow , Waspaloy – Process speed: slow, Zinc – Process speed: normal.

Machine tools are of multiple heads with single power supply. Their construction is similar to that of ECM tools. Typical applications of this process include Medical Industry, Surgical Instruments, Guidewire catheters, Laparoscopic tools, Arthroscopic cutters, Cautery probes, Biopsy cups, Spatulas, Surgical blades, Hypodermic needles, Cannulas, Clamps, Forceps, Needle holders, Retractors, Scissors etc.

3. Mathematical modeling of electrochemical deburring

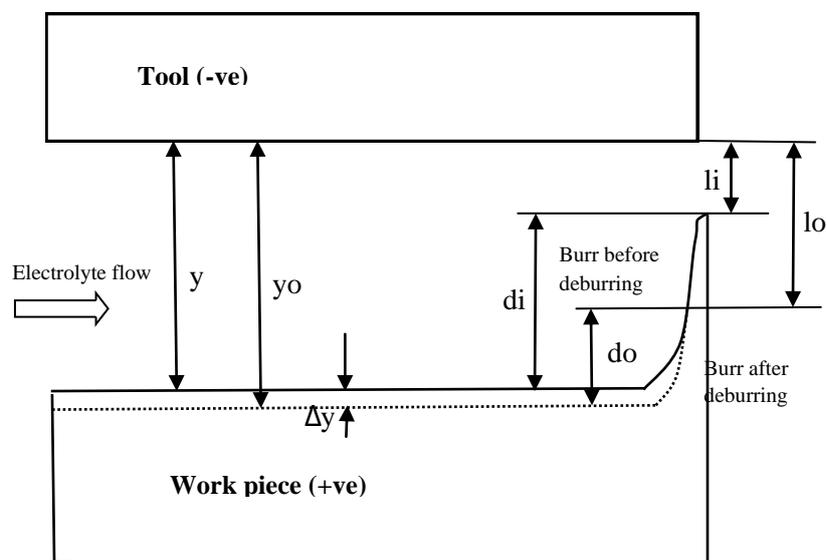


Figure 2. Schematic representation of electrochemical burr removal

The electrolyte is assumed to flow in a direction normal to the feed across the gap between the two electrodes. It is also assumed that the properties of electrolyte remain unchanged in the other direction of metal dissolution.

If the material removal is in the direction of feed tool advancement or feed,

Then,

$$MRR_t = \frac{J E \eta}{\rho_a F} \quad (1)$$

' J ' is the current density $\frac{I}{A_w}$ A/mm², ' ρ_a ' is the density in g/mm³ of the anode, ' E ' is the $\frac{A}{Z}$ gm equivalent weight of the material. ' F ' is the Faraday's constant 96500 and ' η ' is the efficiency.

In electrochemical deburring, a properly shaped electrode tool concentrates the electric current on those areas of the work piece from which preferential burr removal is desired. Material removal is controlled by current density in that area. However current density depends on the shape of the electrode tool, and their distance or Inter electrode gap (IEG), a voltage applied and electrical conductivity of the electrolyte flowing through the gap.

$$\text{Current Density} = J = \frac{(V - \Delta V)k^\circ}{y} \quad (2)$$

' k° ' is the electrolytic conductivity $\Omega^{-1}mm^{-1}$, ' ΔV ' is the overvoltage in Volts, ' V ' is the applied voltage in Volts.

Since there is no tool advancement in ECD and feed rate is ' f ' is zero.

$$\frac{dy}{dt} = \frac{(V - \Delta V)k^\circ}{y} \frac{E \eta}{\rho_a F} - f \quad (3)$$

$$\frac{(V - \Delta V)k^\circ}{y} \frac{E \eta}{\rho_a F} = f \quad (4)$$

$$\frac{dy}{dt} = \frac{\dot{m}}{y} - f \quad (5)$$

Here ' \dot{m} ' is the constant

$$\dot{m} = \frac{(V - \Delta V)k^\circ}{1} \frac{E \eta}{\rho_a F} \quad (6)$$

For the stationary tool in ECD,

Feed rate ' $f=0$ ' and expression (5) can be written as

$$\begin{aligned} \frac{dy}{dt} &= \frac{\dot{m}}{y} \\ y \, dy &= \dot{m} \, dt \end{aligned}$$

Upon integrating and simplifying

$$y^2 = 2\dot{m} t + K$$

For initial conditions, $y=y_0$ at $t=0$

$$\begin{aligned} K &= y_0^2 \\ y &= (2\dot{m} t + y_0^2)^{\frac{1}{2}} \quad \text{i.e. the gap increases with the square root of} \\ &\quad \text{time.} \end{aligned}$$

From the fig,

$$y = y_0 + \Delta y, \quad \gg \quad \Delta y = y - y_0$$

$$\Delta y = (2\dot{m} t + y_o^2)^{\frac{1}{2}} - y_o \quad (7)$$

Refer to the figure,

If ' l_i ' is the gap before deburring, ' l_o ' is the instantaneous gap after deburring,

$l_i = y_o - d_i$, ' d_i ' is the height to be deburred. ' d_o ' is the instantaneous height after deburring.

$$l_o = (2\dot{m} t + l_i^2)^{\frac{1}{2}}$$

Substituting the value of ' l_i ' in the above equation,

$$l_o = (2\dot{m} t + (y_o - d_i)^2)^{\frac{1}{2}}$$

Instantaneous burr height can be expressed as ' d_o '

$$d_o = y - l_o$$

Combining the equations, we get

$$d_o = y = (2\dot{m} t + y_o^2)^{\frac{1}{2}} - (2\dot{m} t + (y_o - d_i)^2)^{\frac{1}{2}} \quad (8)$$

After simplifying and rearranging,

The deburring time can be given by,

$$t = \left\{ \frac{d_i^2 - d_o^2}{8 \dot{m} d_o^2} (d_i^2 - d_o^2) + 4y_o(y_o - d_i) \right\} \quad (9)$$

And base metal removal will be,

$$\Delta y = \left\{ \left(y_o^2 + \frac{d_i^2 - d_o^2}{4 d_o^2} (d_i^2 - d_o^2) + 4y_o(y_o - d_i) \right)^{\frac{1}{2}} \right\} \quad (10)$$

4. Hydrodynamics of the process

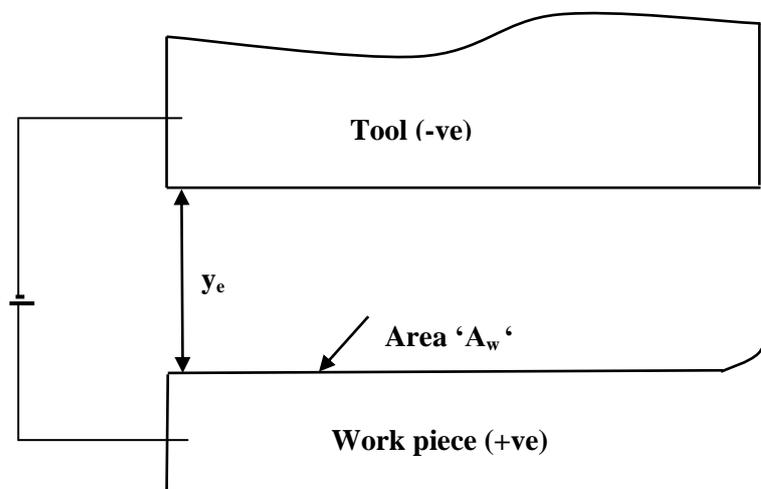


Figure 3. Schematic diagram of electrodes for electrolytic action.

It is clear that material removal rate is directly dependent on the current density and possible heat generation at gap during electrolytic reactions can be mathematically expressed as below. If the heat produced is given by ' H ',

$$H = I^2 R_e \quad \text{and} \quad R_e = \frac{v_e y_e}{A_w} \quad (11)$$

' $A_w = b_w l_w$ ' Area of the work piece.

If ' C_{pe} ' is the average specific heat of the electrolyte and the specific resistivity ' v_e ' of the electrolyte is assumed to be constant. ' y_e ' gap through electrolyte is flowing.

$$I^2 R_e = 4.1868 q_e \rho_e C_{pe} (\theta_o - \theta_i) \quad (12)$$

' q_e ' is the flow rate of the electrolyte, ' ρ_e ' is the density of the electrolyte, θ_o and θ_i are the outlet and inlet temperature of the electrolyte.

If we consider again ' J ' is the current density given by,

$$J = \frac{I}{A_w} \frac{A}{mm^2} \quad (13)$$

$$J^2 A_w v_e y_e = 4.1868 q_e \rho_e C_{pe} (\theta_o - \theta_i)$$

$$J^2 = \frac{4.1868 q_e \rho_e C_{pe} (\theta_o - \theta_i)}{A_w v_e y_e}$$

Flow of the electrolyte,

$$q_e = \frac{J^2 A_w v_e y_e}{4.1868 \rho_e C_{pe} (\theta_o - \theta_i)}$$

In case of rectangular electrode,

$$q_e = U b_w y_e \quad (14)$$

$$U b_w y_e = \frac{J^2 A_w v_e y_e}{4.1868 \rho_e C_{pe} (\theta_o - \theta_i)}$$

$$U = \frac{J^2 A_w v_e}{4.1868 \rho_e C_{pe} (\theta_o - \theta_i) b_w} \quad (15)$$

is the velocity of the electrolyte.

If ' V ' is the applied Voltage,

$$I = \frac{V}{R_e} = \frac{V A_w}{v_e y_e}$$

Then,

$$U = \frac{V^2 l_w}{4.1868 v_e y_e^2 C_{pe} (\theta_o - \theta_i) b_w} \quad (16)$$

In the mathematical relationships, the electrolytic conductivity is assumed to be constant throughout the gap. Practically it is far from true. It can be altered by local temperature, bubbling, and sludge formation. Presence of Hydrogen bubbles could significantly alter the electrolytic conductivity. If temperature increases the conductivity, hydrogen bubbles will not. The effect of temperature is discussed here in this section. This could alter the inter-electrode gap.

Hydrogen gas bubble evolution at the cathode is governed by current density on its surface. Hydrogen bubbles are carried away by the flowing electrolyte, their concentration will decrease in the flowing direction of the electrolyte. The net effect of the hydrogen bubble is that to decrease the electrical conductivity of the electrolyte and eventually metal removal rate at the anode. The size and distribution of the bubbles can affect the electrolytic conductivity but very difficult to estimate the same under complex hydrodynamic conditions.

5. Conclusions

The development of mathematical model here is an analysis tool capable of predicting results with good accuracy. The model predicted here can be utilized to compare experimental results.

- (1) Differences in the material removal rate due to factors here can be attributed to the reasons highlighted.
- (2) The temperature of the electrolyte and at the interface can be estimated which is responsible for optimum machining conditions.
- (3) Instantaneous burr height and base metal removal can be theoretically predicted.
- (4) Theoretically, it would take infinite time for deburring. But in practice time of deburring will generally be in seconds and mathematically computed with empirical relations.

Future scope of work can be on a prediction of volume of air bubbles and variation of electrolytic conductivity.

6. References

- [1] Sarkar S, Mitra S, Bhattacharya B. Mathematical modeling for controlled electrochemical deburring (ECD), *Journal of Materials Processing Technology* 2004, Vol. **147**, 241–246.
- [2] Rajurkar K P, Sundaram M M, Malshe A P. Review of Electrochemical and Electro discharge machining. *Procedia CIRP* **6** (2013) 13-26.
- [3] Jain V K. Electrochemical Allied Processes. *ASM Handbook*, Vol **13A** Corrosion fundamentals, Testing and Protection, p153-156.
- [4] Rajurkar K P, Jerzy Kozak, Arindam Chatterjee. *ASM Handbook*, Vol **5** Surface Engineering. 110-117.
- [5] Aurich J C, Dornfeld D, Arrazola P J, Franke V, Leitz L, Min S. Burrs-Analysis, Control and Removal. *CIRP Ann. Manuf. Technol.* 2009, **58**, 519–542.
- [6] Niknam S A, Zedan Y, Songmene V. Machining Burrs Formation & Deburring of Aluminium Alloys. dx.doi.org/10.5772/58361.
- [7] Mitra S, Sarkar S and Shome D (2005), Experimental study of electrochemical deburring (ECD) process *International Conference on Mechanical Engineering* 2005, 28– 30.

- [8] Mitra S, Sarkar S. Experimental Investigation on Electrochemical Deburring (ECD) Process. *Journal of Material Processing Technology*, **75**(1998), 198-203.
- [9] Bhattacharya B, Munda J, Malapathi M. Advancement in electrochemical micro-machining. *International journal of Machine tool and Manufacture*. **44**(2004),1577-1589.
- [10] Machinability data center. *Machining Data handbook* 3rd edition, ISBN-0936974-02-8, 11. 3(1980).
- [11] Gillespie L K, *Deburring and Edge finishing hand book*, ISBN-13: 978-0872635012.