Effect Of Voltage Variation On MRR For Stainless Steel EN Series 58A (AISI 302B) In Electrochemical Machining: A Practical Approach

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Abstract

The machining of complex shaped designs was difficult earlier, but with the advent of the new machining processes incorporating in it chemical, electrical & mechanical processes, manufacturing has redefined itself. This paper intends to deal with one of the revolutionary process called Electro Chemical Machining (ECM) which is unconventional process. New materials which have high strength to weight ratio, heat resistance and hardness and also complex shapes and need for accuracy demand newer type of machining process. These processes are called unconventional machining processes. ECM removes material without heat. Almost all types of metals can be machined by this process. In today's high precision and time sensitive scenario, ECM has wide scope of applications.

The said paper is a experimental study of effect of voltage variation on MRR for Stainless steel EN Series 58A (AISI 302B)

A comparative study of calculation for MRR on theoretical as well practical basis are given in tabular format with graphical representation. The said experimentation is carried out at Micromachining Cell I I T Bombay in the month of Dec 2008.

Keywords: ECM, Electrolyte, EMM, Metal removal Rate, (MRR), Unconventional machining.

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1. Introduction

Electrochemical Machining ECM[1] is a process based on the controlled anodic dissolution process of the work piece anode, with the tool as the cathode, in an electrolytic solution. The electrolyte flows between the electrodes and carries away the dissolved metal. The main advantages of ECM are:

1. Machining does not depend on the hardness of the metal;
2. Complicated shapes can be machined on hard surfaces;
3. There is no tool wear;
4. It is environmental friendly.

When this process is applied to the micromachining range for manufacturing of micro components or features, it is referred as electrochemical micromachining EMM.[5]

2. Electrolysis

Electrolysis[8] is the name given to the chemical process which occurs, for example, when an electric current is passed between two conductors dipped into a liquid solution. Fig 1 shows the electrolysis process with iron rod as a electrodes and electrolyte is the solution of Sodium Chloride (NaCl) with water.

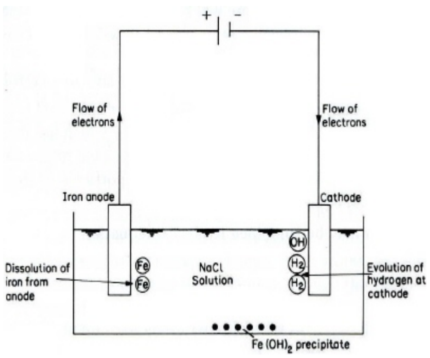

Fig 1. Electrolysis with Nacl

Reactions that occur during the electrolysis of iron (Figure 1) are as follows. The anodic reaction is ionizing of iron:

$Fe \Longrightarrow Fe^{2+}(aq) + 2e^-$

At the cathode, the reaction is likely to be the generation of hydrogen gas and the production of hydroxyl ions:

$H_2O + 2e^- \Longrightarrow H_2 + 2OH^-$

The net reaction is thus:

$Fe + 2H_2O ==> Fe(OH)_2(s) + H_2$

The ferrous hydroxide may react to form ferric hydroxide:

$4Fe(OH)_2 + 2H_2O + O_2 ==> 4Fe(OH)_3$

The system of electrodes and electrolyte is referred to as the electrolytic cell, whilst the chemical reactions which occur at the electrodes are called the anodic or cathodic reactions or processes.

2.1 Mechanism of electrolysis process

Electrolytes are different from metallic conductors of electricity in that the current is carried not by electrons but by atoms, or group of atoms, which have either lost or gained electrons, thus acquiring either positive or negative charges. Such atoms are called ions. Ions which carry positive charges move through the electrolyte in the direction of the positive current that is, toward the cathode and are called cations. Similarly, the negatively charged ions travel toward the anode and are called anions. The movement of the ions is accompanied by the flow of electrons, in the opposite sense to the positive current in the electrolyte, outside the cell, as shown in Figure 1and both reactions are a consequence of the applied potential difference that is voltage from the electric source.[8]

3. Electrochemical Machining (ECM)

Fig 2 shows a schematic diagram of Electrochemical machining set up with all accessories.

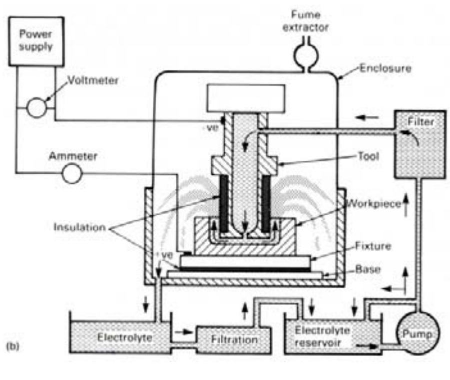

Fig 2 . ECM Setup

Fig shows the schematic set up of ECM[1] in which two electrodes are placed at a distance of about 0.5to 1mm & immersed in an electrolyte, which is a solution of sodium chloride[8]. When an electrical potential of about 20V is applied between the electrodes, the ions existing in the electrodes migrate toward the electrodes.

Positively charged ions are attracted towards the cathode & negatively charged towards the anode. This initiates the flow of current in the electrolyte. This process continues and tool reproduces its shape in the work piece (anode). The high current densities promote rapid generation of metal hydroxides and gas bubble in the small spacing between the electrodes.

4. Electrochemical Micromachining (EMM)

Fig3 shows drilling operation with EMM.

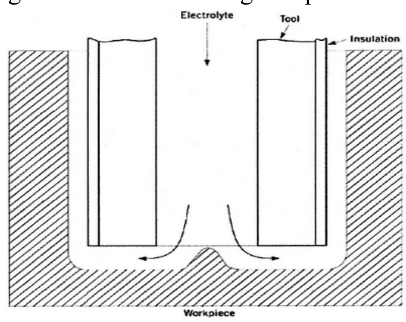

FIG 3. EMM Process

When the ECM process is applied to micro-machining range for manufacturing ultra precision shapes, it is called Electrochemical Micro-machining (EMM).[2]. There are numerous issues that come into play while machining at micro-scales.

This present work is aimed at understanding the principle, the various process parameters that influence the machining process and influence of voltage variation on MRR. Finally a comparison between theoretical and actual MRR is given with graphical representation. In addition to it percentage error in MRR is also calculated.

5. Process parameters in ECM

Following are the some parameters which govern the ECM.

5.1 Voltage

The nature of applied power supply is of two types: DC (full wave rectified) and pulse DC. A full wave rectified DC supplies continuous voltage and a pulse generator is used to supply pulses of voltage with specific on-time and off-time.

In EMM, the use of pulse voltage has the following advantages:[7]

- The waste sludge can be removed during the off-time, as the formation of the sludge in the narrow gap might lead to clogging and deposition on the tool, which will have an adverse effect on the machining process.
- It prevents the electrolyte from reaching high temperatures. The use of sufficient off-time allows it to cool down to normal temperature.
- The gap checking and tool repositioning can also be conducted during these pulse pauses to establish a given gap size, before the arrival of the next pulse, leading to a

significant reduction in the indeterminacy of the gap and, hence, of the shaping accuracy.

• The use of pulsed voltage also improves the surface finish criteria of EMM.

The material removal rate (MRR) is proportional to the applied voltage. But, the experimental values were found to be varying non-linearly with voltage. This is mainly because of less dissolution efficiency in the low voltage zone as compared to the high voltage zone.

However continuous voltage supply is used for our experimentation work.

5.2 Inter-electrode gap

The gap between the tool (cathode) and the work piece (anode) is important for metal removal in micro-machining processes.[6] It plays a major role for accuracy in shape generation.

5.3 Electrolyte and its concentration

ECM electrolyte is generally classified into two categories:

a. Passivity electrolyte containing oxidizing anions e.g. sodium nitrate and sodium chlorate, etc.

b. Non-passivity electrolyte containing relatively aggressive anions such as sodium chloride.

Passivity electrolytes are known to give better machining precision. This is due to their ability to form oxide films and evolve oxygen in the stray current region. Most of the investigation researchers recommended $NaClO_3$, $NaNO_3$ and NaCl solution with different concentration for electrochemical micro-machining (EMM). The pH value of the electrolyte solution is chosen to ensure good dissolution of the work piece material during the process without the tool being attacked. It is usual to work with natural *NaCl* electrolyte solution. The metal removal rate (MRR) increases with increase in electrolyte concentration.

6. Experimentation Work

Experimental runs are taken on ECM setup by varying voltage and keeping IEG constant. Theoretical and actual MRR is calculated for various readings and their comparison is given in a tabular form. MRR in volumetric decrease, as well as weight loss is also calculated and presented in a tabular format. The other governing parameters are assumed to be constant with NaCl as a electrolyte with 30gms/ Ltr concentration.

6.1Experimental setup

Fig4 shows a photograph of the experimental set of ECM on which the said experimentation is carried out.

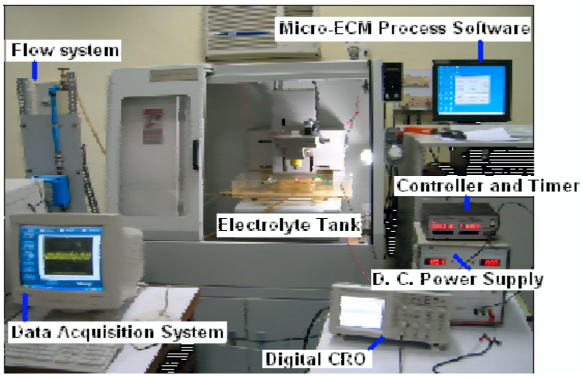

Fig 4. Experimental setup of ECM at IIT Bombay

Occurance of ECM process is shown in fig 5, in which a photograph of tool, work piece and electrolyte flow is shown.

Fig 5. Electrochemical Machining Process going on.

Fig 6 shows the photo graph DC power supply unit through which controlled voltage supply is given to set up.

Fig 6. D C Power Supply of ECM set up

7. Process parameters

- Tool : Brass (2mm diameter)
- Electrolyte : NaCl (30gm/liter)
- Flow rate : 25 Ltr/hr
- Work piece : Stainless steel EN Series 58A (AISI 302B)
- Density of alloy : 8 g/cm^3

7.1 Components of alloy

Table No 1 shows the various components of alloy

stainless steel EN Series 58A (AISI No 302B)

Table No 1

Element	Composition (%)	Density (g/cm^3)	Atomic weight	Valency
Carbon C	1.18	2.26	12.011	2
Manganese Mn	1.43	7.43	54.938	2
Silicon Si	.44	2.33	28.086	4
Chromium Cr	18.65	7.19	51.996	2
Nickel Ni	8.20	8.90	58.693	3
Iron Fe	69.85	7.86	55.845	2

7.2 Work piece and Tool

Fig 7 shows a photograph of work piece and tool prior to machining and fig 8 shows a photograph of work piece after machining.

Fig 7. Work piece and tool before Machining

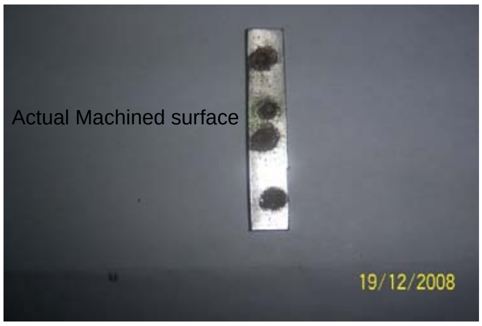

Fig 8. Work piece after machining

7.3 Observation table for varying Voltage

Table No 2 shows the readings and calculated MRR for varying voltage while IEG was kept constant during all readings. MRR is given in g/sec as well as cm^3/sec.

Table No 2

Sr no.	I.E.G. (mm)	Voltage (Volts)	Current (Amp)	Initial wt. gms	Final wt gms	ΔT (min)	MRR (g/sec)	MRR (cm^3/sec)
1.	1	20	0.22	8.606	8.553	15	5.889 X10^{-5}	7.361 X10^{-6}
2	1	30	0.27	8.553	8.493	15	6.61 X10^{-5}	8.264 X10^{-6}
3	1	35	0.29	8.493	8.429	15	7.01 X10^{-5}	8.762 X10^{-6}
4	1	40	0.31	8.429	8.360	15	7.667 X10^{-5}	9.584 X10^{-6}
5	1	45	0.33	8.360	8.280	15	8.889 X10^{-5}	11.11 X10^{-6}

8. Graphical Representation

Fig 9 shows a graph of actual MRR Vs voltage.

Voltage is on X axis while MRR is given on Y axis.

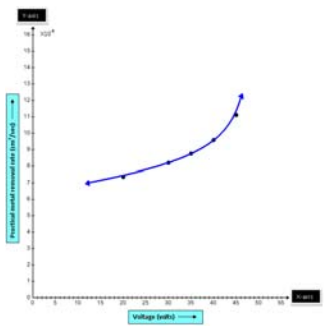

Fig 9. Graph for Actual MRR Vs Voltage

9. Theoretical Formulae for MRR

$$MRR = \frac{A*I}{\rho Z F} \quad (cm^3/sec)$$ … **For metals**

$$MRR = 0.1035X10^{-2}\left\{\frac{1}{\sum \frac{XiZi}{Ai}}\right\} \quad (cm^3/A\ sec)$$ … **For alloys**

Where--

MRR : Metal Removal Rate
A : Atomic Weight of metal
I : Current flowing in the circuit
ρ : Density of the metal
Z : Valancy of dissolution
F : Faraday's Constant
Xi : Composition of Element in Alloy

10. Actual MRR

$$\text{MRR in wt (g/sec)} = \frac{\text{Initial weight - Final weight}}{\text{Time}}$$

10.1 Calculations for Actual MRR

MRR For IEG = 1mm (constant)

and Voltage = Varying

Actual MRR

$$= \frac{8.606 - 8.553}{15X60}$$

$$= 5.889X10^{-5} \text{ g/sec}$$

Density:

$\rho = 8 \text{ g/cm}^3$

$$\text{MRR volumetric } (cm^3/sec) = \frac{MRR}{\rho} \frac{(g/sec)}{(g/cm^3)}$$

$$= \frac{5.889X10^{-5}}{8}$$

$$= 7.361X10^{-6} \text{ cm}^3/sec$$

10.2 Theoretical MRR

$$MRR = \frac{A*I}{\rho Z F} \quad (cm^3/sec).$$ … For metals.

$$MRR = 0.1035X10^{-2}\left\{\frac{1}{\sum \frac{XiZi}{Ai}}\right\} \quad (cm^3/A\ sec)$$ … For alloys.

$$MRR = \frac{0.1035X10^{-2}}{8} X \left\{\frac{1}{\frac{69.91X2}{55.845} + \frac{1.18X2}{12} + \frac{1.43X2}{54.94} + \frac{.44X4}{28.04} + \frac{18.65X2}{51.99} + \frac{8.21X3}{58.4}}\right\}$$

$$MRR = 3.468X10^{-5} \text{ cm}^3/Asec$$

$$MRR = 3.468X10^{-5}X0.22 \text{ cm}^3/sec$$

$$MRR = 7.629X10^{-6} \text{cm}^3/sec$$

Theoretical MRR = $7.629X10^{-6}$ cm^3/sec

MRR in g/sec = MRR (cm^3/sec) X ρ (g/cm^3)

$$= 7.629X10^{-6} X 8$$

$$= 6.103X10^{-5} \text{g/sec}$$

$$\%error = \frac{\text{Theoretical MRR – Practical MRR}}{\text{Theoretical MRR}} X100$$

$$= \frac{7.629X10^{-6} – 7.361X10^{-6}}{7.629X10^{-6}}$$

$$= 3.513\%$$

10. 3 Graphical Representation

Fig 10 shows graph of theoretical MRR Vs Voltage. Voltage is on X axis while MRR is given on Y axis.

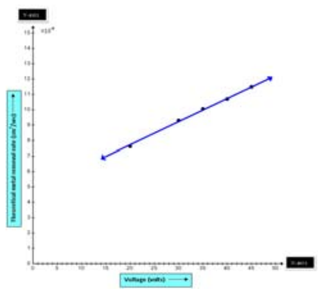

Fig 10. Graph for Theoretical MRR Vs Voltage

11.Comparison of Practical v/s Theoretical values of MRR

Table No 3 shows the comparison of practical and Theoretical values of MRR with percentage error for stainless steel .

Table No 3

Sr no.	Voltage (Volts)	I.E.G. (mm)	Current (Amp)	MRR practical (g/sec)	MRR practical (cm^3/sec)	MRR Theorestical (g/sec)	MRR theoretical (cm^3/sec)	% error
1.	20	1	0.22	5.889 $X10^{-5}$	7.361 $X10^{-6}$	6.10 $X10^{-5}$	7.629 $X10^{-6}$	3.51 %
2	30	1	0.27	6.61 $X10^{-5}$	8.264 $X10^{-6}$	7.44 $X10^{-5}$	9.30 $X10^{-6}$	11.13 %
3	35	1	0.29	7.01 $X10^{-5}$	8.762 $X10^{-6}$	8.04 $X10^{-5}$	10.05 $X10^{-6}$	12.8 %
4	40	1	0.31	7.667 $X10^{-5}$	9.584 $X10^{-6}$	8.56 $X10^{-5}$	10.7 $X10^{-6}$	10.46 %
5	45	1	0.33	8.889 $X10^{-5}$	11.11 $X10^{-6}$	9.19 $X10^{-5}$	11.49 $X10^{-6}$	3.31 %

12. Conclusion

The experimentation work consist of study the influence of process parameters on machining criteria such as MRR . Some of the process parameter such as machining voltage and inter electrode gap (IEG) are successfully controlled with the help of unique setup available at IIT Bombay. The machining voltage and IEG was considered for the experimentation to study their influence on MRR. With gradual increase in voltage MRR increases. IEG (Inter Electrode gap) variable is maintained constant during the whole experimentation. The machining voltage 45V (0.33A) gives the appreciable amount of MRR.

The said experimentation is carried out by varying voltage and considering other process parameters as constant one. By considering other process parameters, the said experimentations can be continued to find optimum results. Secondly the difference between the values of theoretical MRR and Practical MRR are also required to give some thought, so that % error can be reduced.

13.Acknowledgement

The Electrochemical Machining set up which was used for said experimentation is situated at Mechanical Engineering Department of IIT Bombay. We are very much thankful to **Dr. S. S. Joshi** In Charge of said laboratory for permitting us to do experimentation on said setup. He gave us his precious time and advice regarding our work. **Mr. Deepak Marla** guided us to carry out the experimentation. We are very much thankful to all those who have helped us for this task.

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