Experimental Analysis of Electro Chemical Micro Machining on Nickel

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Abstract**—** The advancement in the field of mechanical engineering is very essential to meet the growing demands of the industry. Electro Chemical Micro Machining (ECMM) machines are used to cut metals of any hardness or that are difficult or impossible to cut with traditional methods. These machines also specialize in cutting complex contours or geometries that would be difficult to produce using conventional cutting methods. survey has revealed that a little research has been conducted to obtain the combination of optimal levels of machining parameters that yield the maximum MRR and best machining quality in machining of difficult to machine materials like Nickel The objective of the present research work is to investigate the effects of the various ECMM process parameters on the MRR and dimensional deviation to obtain the optimal sets of process parameters to produce efficient high quality machining. The experimental setup for this research on ECMM consists of Electrolyte tank, non-corrosive work holding platform, Feeding device actuated with stepper motor, Microprocessor based machine control unit and Power supply system. The Taguchi technique has been used to investigate the effects of the ECMM process parameters and subsequently to predict sets of optimal parameters for maximum MRR. The working ranges and levels of the ECMM process parameters are found using one factor at a time approach. The ANOVA has been used to find optimal combination of machining parameters. The confirmation experiments are conducted based on the predicted levels of process parameters.

Keywords**— Electro Chemical Micro Machining (ECMM), MRR, Taguchi technique**

I. INTRODUCTION

The process of creativity proceeds by way of research, design and development. The research work concerned with creation of new system, process, and equipment for the benefit of mankind is engineering. Research as the art of executing a partial application of scientific knowledge by utilizing the established facts, laws and principles of nature for the benefit of human rays. The new system emerging from innovation may be constituted by mechanical, electro mechanical, hydraulic, thermal, or other such elements. In these lines, this research tries to innovate the process of Electro Chemical Micro Machining (ECMM) for Nickel and its alloys. Electrochemical machining (ECM) was developed during late 1950s and early 1960s and used to machine difficult-to-cut materials in aerospace and other heavy industries for shaping and finishing operations [6]. It is an anodic dissolution process based on the phenomenon of electrolysis, whose laws were established by Michael Faraday. In ECM, electrolytes serve as conductor of electricity. ECM offers a number of advantages over other machining methods. The ECM technique now plays an important role in the manufacturing of a variety of parts ranging from machining of large metallic pieces of complicated shapes to opening of windows in silicon that are a few microns in size. When ECM is performed at micro meter level (material removal that ranges from 1-999 µm), it is known as ECMM [1]. ECMM is used for making smaller size components with high precision. Advanced micro machining process consists of various ultra-precision activities to be performed on very small and thin work pieces [2] The ECMM process can be effectively used for high precision machining operations such as removal of micro burrs, making patterns in foils and 3D micromachining. These qualities and capabilities of ECMM process makes it useful in many industries where difficult-to-cut materials are processed. The electrolyte is constantly flushed in the gap between tool and the work piece to remove contaminated electrolyte. The non-removal of electrolyte with suspended precipitate from the machining zone leads to accumulation of debris. This accumulation cause short circuit between the electrodes. The electrolyte also carries away hydrogen bubbles created at the machining zone. The tool electrode is advanced into work piece for the machining to be carried out. A pumping system fitted with electrolyte filter is used to circulate the electrolyte as the electrolyte carries away machining waste along with the heat [3]

A. *Mechanism of Material Removal in ECMM*

Atom-by-atom removal of metal by anodic dissolution is the basic principle underlying electrochemical metal removal process. The movement of the ions is accompanied by electrons flow in the opposite direction to the positive current in the electrolyte [4]. The reactions are the consequence of the applied potential difference, that is, voltage from the electric source. The phenomena can be embodied in Faraday's laws of electrolysis.

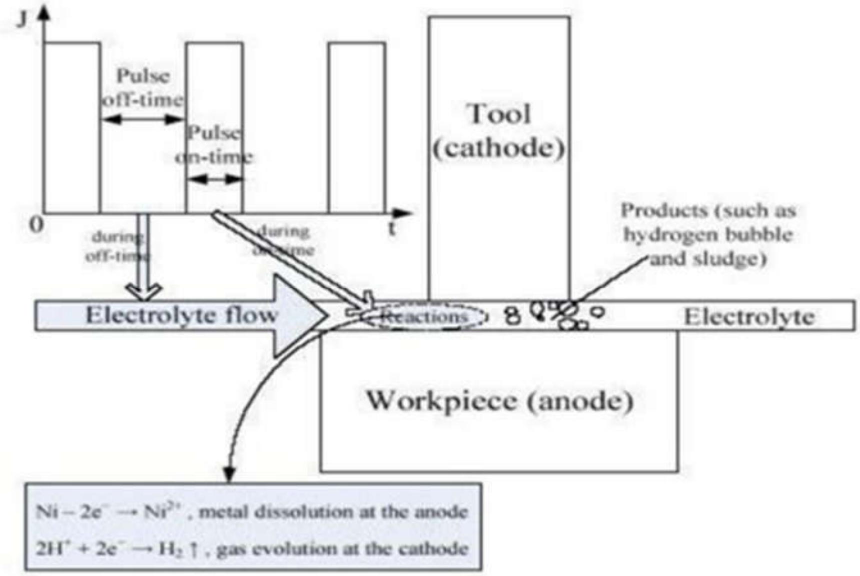

Fig.1 1.1: Physical Model of ECMM

Ion dissolution valence is required in describing the dissolution electrochemical process and calculating material removal according to Faraday's law. TABLE I shows the dissolution valences of some metals in different metal electrolyte. Ions valence can be varied in different solutions and process conditions [5]. The fig.2 shows the mechanism of ECMM. TABLE II presents the comparison between ECM and ECMM.

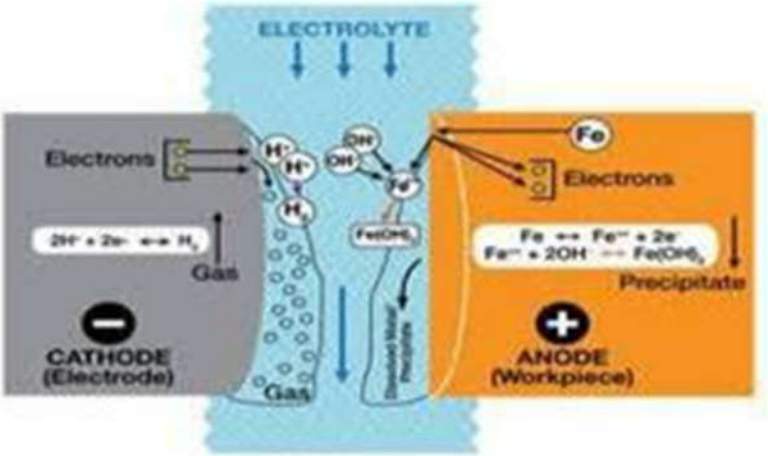

Fig.2 1.2: Mechanism of ECMM

TABLE 1.1 I

DISSOLUTION VALENCE FOR DIFFERENT METALS

Metal	Electrolyte	Dissolution Valence
Ni	NaCl	2
Ni	NaNO3	2*
Fe	NaCl	2 and 3
Fe	NaNO3	2*
Cr	NaCl	6
Cr	NaNO3	6

**Accompanied by oxygen evolution*

TABLE 1.2: II

COMPARISON BETWEEN ECM AND ECMM

Parameters	**ECM**	**ECMM**
Voltage	10-30 V	< 10 V
Current density	20-200 A/cm^2	75-100 A/cm^2
Power supply	Continuous / pulsed	Pulsed
Frequency	Hz-KHz range	KHz-MHz range
Electrolyte flow	10-60 m/s	< 3 m/s
Tool size	Large to medium	Micro
Inter electrode gap	100-600 um	5-50 um
Surface finish	Good	Excellent

The micro machining of Nickel and its alloys can be difficult using traditional machining techniques as they easily harden during machining. High pressure is developed between the tool and the work piece during machining. Such high pressure produces a stressed layer of deformed metal on the surface of the work piece. This deformation causes a hardening effect on the surface of the work piece that slows down further machining. Due to this reason, age-hardened Nickel is machined using an aggressive but slow cut with a hard tool that minimizes the number of passes required. The application of ECMM for Nickel alloy is more suitable but it cannot be applied effectively unless the process parameters are optimized.

The levels of process parameters for experimentation is generally selected either based on the experience or from the propriety machining handbook. In most cases, selected parameters are conservative and far from optimum. Extensive and laborious experimentation involving huge time and cost is required to select the optimum parameters without optimization technique. Hence, it is essential to use suitable optimization technique to study the complete range of level of process parameter with least number of experiments. The analysis of variance (ANOVA) is used to verify statistical significance of the process parameters on MRR is used to derive the optimized values of process parameters for the maximum MRR. The objective of this research is to study the influence of ECMM process parameters such as electrolyte concentration, machining voltage, machining current, duty cycle and frequency on MRR of Nickel.

II. MATERIALS AND METHODS:

Nickel is used in many specific and recognizable industrial and consumer products, including stainless steel, alnico magnets, coinage, rechargeable batteries, electric guitar strings, microphone capsules, and special alloys. It is also used for plating and to produce green tint in glass. Nickel is preeminently an alloy metal, and its chief use is in the nickel steels and nickel cast irons, of which there are many varieties.

The factors which make nickel and its alloys valuable commodities include strength, corrosion resistance, high ductility, good thermal and electric conductivity, magnetic characteristics and catalytic properties. Nickel, above 355 °C becomes non-magnetic material (Curie temperature). The unit cell of nickel is a face centered cube with the lattice parameter of 0.352 nm giving an atomic radius of 0.124 nm. Nickel belongs to the transition metals and is hard and ductile.

TABLE 4.4 III
MISCELLANEOUS PROPERTIES OF NICKEL

Crystal structure	face-centered cubic
Magnetic ordering	ferromagnetic
Electrical resistivity	(20 °C) 69.3 n ·m
Thermal conductivity	90.9 W·m^{1}·K ^{1}
Thermal expansion	(25 °C) 13.4 µm·m^{1}·K ^{1}
Speed of sound (thin rod)	(r.t.) 4900 m·s^{1}
Young's modulus	200 GPa
Shear modulus	76 GPa
Bulk modulus	180 GPa
Poisson ratio	0.31
Mohs hardness	4.0
Vickers hardness	638 MPa
Brinell hardness	700 MPa

III. EXPERIMENTAL ANALYSIS

The experimental setup for this research on ECMM consists of Electrolyte tank, non-corrosive work holding platform, Feeding device actuated with stepper motor, Microprocessor based machine control unit and Power supply system. This setup is capable of maintaining an accuracy of 4 microns in the machining process. The experiments were conducted on 0.15 mm thick specimens made up of Nickel, SDSS and Inconel 600 to find the optimum combination of machining parameters viz., Electrolyte concentration, Machining Voltage, Machining Current, Duty cycle and Frequency. The following levels of the process parameters are selected for the present study.

Table 5.1 IV
PROCESS PARAMETERS AND THEIR LEVELS – NICKEL

Factor	**EC**	**V**	**C**	**DC**	**F**
Level 1	0.1	3.5	0.1	33.33	30
Level 2	0.2	5.0	0.3	50.00	40
Level 3	0.3	6.5	0.5	66.66	50

EC: Electrolyte Concentration (mol/lit), V: Voltage (Volt),

C: Current (Ampere), DC: Duty Cycle (%), F: Frequency (Hz).

The entire set of experiments is carried out in a phased manner. The experiments in each phase were repeated two times in order to achieve mean values. The analysis and verification of experimental results using Taguchi methodology is concluded that the major factor affecting the MRR on Nickel is Machining Current, on SDSS is Duty cycle. It is inferred from the experiment that the reduction in % of Nickel present in the alloy, the other processing factors like Duty Cycle and Electrolyte concentration becomes the major parameter affecting the MRR. The orthogonal array of process parameters shown in TABLE V.

Table V
ORTHOGONAL ARRAY OF PROCESS PARAMETERS - NICKEL

Exp. No	Electrolyte Concentration (mol/lit)	Machining Voltage (Volts)	Machining Current (Amps)	Duty cycle (%)	Frequency (Hz)
1	0.1	3.5	0.1	33.33	30
2	0.1	5.0	0.3	50.00	40
3	0.1	6.5	0.5	66.66	50
4	0.2	3.5	0.1	50.00	40
5	0.2	5.0	0.3	66.66	50
6	0.2	6.5	0.5	33.33	30
7	0.3	3.5	0.3	33.33	50
8	0.3	5.0	0.5	50.00	30
9	0.3	6.5	0.1	66.66	40
10	0.1	3.5	0.5	66.66	40
11	0.1	5.0	0.1	33.33	50
12	0.1	6.5	0.3	50.00	30
13	0.2	3.5	0.3	66.66	30
14	0.2	5.0	0.5	33.33	40
15	0.2	6.5	0.1	50.00	50
16	0.3	3.5	0.5	50.00	50
17	0.3	5.0	0.1	66.66	30
18	0.3	6.5	0.3	33.33	40

IV. RESULTS AND DISCUSSION:

The ECMM experiments are conducted with brass wire tool of 250 microns diameter for Nickel. The tool used for machining SDSS and Inconel 600 is stainless steel wire of 250 microns diameter. In order to achieve proper circularity of machined holes, the anode tool is properly ground. The test job specimens are kept uniform in size for Nickelmeasuring 50 mm × 25 mm × 0.15 mm. The test specimens are prepared using WEDM machine and after machining, the specimens treated to retain their originality. The electrolyte used for Nickel and its alloys is NaNO3. The ECMM experiments were conducted twice in each combination of process parameters to study its effect over MRR. From the trial 1 and trial 2 experiments, the average MRR is calculated and tabulated for Nickel in TABLE VI.

TABLE VI
EXPERIMENTAL RESULTS FOR MRR - NICKEL

Exp. No.	Machining Time in Trial 1	Machining Time in Trial 2	MRR Trial 1	MRR Trial 2	Average MRR
1	21.0	15.0	0.001660	0.001604	0.001632
2	8.0	13.0	0.002127	0.002119	0.002123
3	4.0	3.5	0.006223	0.006391	0.006307
4	14.0	22.0	0.001815	0.001863	0.001839
5	6.5	5.5	0.004089	0.003977	0.004033
6	2.8	2.5	0.006767	0.006639	0.006703
7	10.5	19.5	0.002869	0.002879	0.002874
8	2.5	3.8	0.009628	0.009526	0.009577
9	5.5	5.0	0.003399	0.003053	0.003226
10	8.0	11.0	0.003722	0.003726	0.003724
11	12.0	16.0	0.001343	0.001395	0.001369
12	8.0	4.8	0.004621	0.004729	0.004675
13	5.5	8.0	0.004832	0.004782	0.004807
14	4.3	9.8	0.004378	0.004426	0.004402
15	15.0	22.0	0.001873	0.001887	0.001880
16	5.0	5.5	0.003884	0.003978	0.003931
17	5.5	4.3	0.003399	0.003387	0.003393
18	3.0	4.0	0.006474	0.006618	0.006546

The machining time, MRR and dimensional deviation are given for Nickel in TABLE VII.

TABLE VII
EXPERIMENTAL RESULTS - NICKEL

Exp. No	Machining time (min)	Material Removal Rate (mm^3/min.)	Dimensional Deviation (microns)
1	18.00	0.001632	29
2	10.50	0.002123	13
3	4.00	0.006307	20
4	18.00	0.001839	21
5	6.00	0.004033	22
6	2.63	0.006703	14
7	15.00	0.002874	25
8	3.13	0.009577	20
9	5.25	0.003226	14
10	9.50	0.003724	25
11	14.00	0.001369	11
12	6.38	0.004675	31
13	6.75	0.004807	22
14	7.00	0.004402	14
15	18.50	0.001880	23
16	5.25	0.003931	15
17	4.88	0.003393	14
18	3.50	0.006546	15

It can be seen from the experimental results of Nickel, the obtained MRR ranges from 0.001369 to 0.009577 mm3/min, while the dimension deviation stood between 11 and 31 microns.

The eighth combination of levels of process parameters, A3B2C3D2E1 gave maximum MRR of 0.009577 mm3/min. At this combination, the machining performance is better with a low dimensional deviation of 20 microns. Hence this combination proved to be the optimum process parameter to produce the maximum MRR on Nickel. The microscopic image of the outcome of 8th experiment is shown as fig. 3.

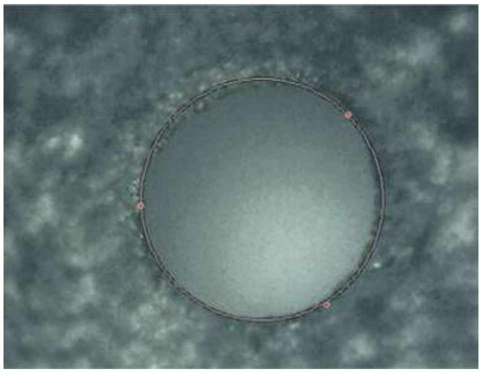

Fig. 3: Image of micro hole machined in 8th experiment *
Parameters: Electrolyte Concentration: 0.3 mol/lit Voltage: 5 Volts Current: 0.5 amps Duty Cycle: 50% Frequency: 30 Hz

The twelfth combination of process parameters EC1V3C2DC2F1 produced an above average MRR (0.004675 mm3/min) with moderate machining time. However, the dimensional deviation has peaked with 31 microns. The microscopic image of the outcome of 12th experiment is shown as fig.4.

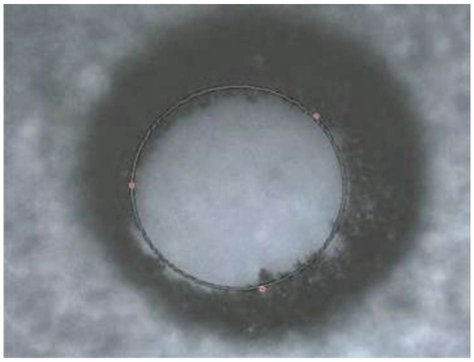

Fig. 4 5.2: Image of micro hole machined in 12th experiment
Current: 0.3 amps Duty Cycle: 50% Frequency: 30 Hz MRR: 0.004675 mm3/min Dimensional Deviation: 31 microns

The process parameters combination EC1V2C1DC1F3 is chosen as the 11th combination in the experimental investigation as shown in the fig.5. This combination yielded the least MRR (0.001369 mm3/min) with 31 microns of dimensional deviation in spite of higher machining time (6.38 min.).

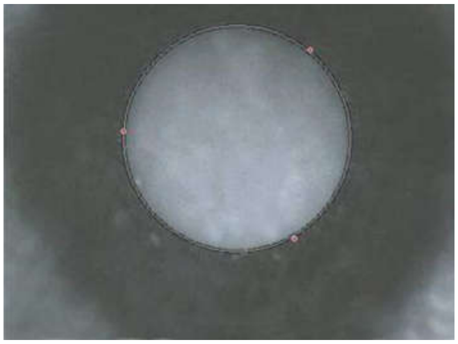

Fig.5: Image of micro hole machined in 11th experiment
Parameters: Electrolyte Concentration: 0.1 mol/lit Voltage: 5 Volts Current: 0.1 Amps Duty Cycle: 33.33% Frequency: 50 Hz
MRR: 0.001369 mm3/min Dimensional Deviation: 11 microns

V. CONCLUSIONS

It is evident from this research work that the dominant process parameter which affects MRR varies based on the Nickel content in the Nickel Alloy. The 100% pure Nickel has shown high rate of dissolution for the higher machining current (C). The entire set of experiments is carried out in a phased manner. The experiments in each phase were repeated two times in order to achieve mean values. The analysis and verification of experimental results are concluded that the major factor affecting the MRR on Nickel is Machining Current. It is inferred from the experiment that the processing factors like Duty Cycle and Electrolyte concentration becomes the major parameter affecting the MRR.

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