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EXPERIMENTAL STUDY OF MRR OF ECM ON STAINLESS STEEL 200 MATERIAL

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Abstract:-Electro chemical machining (ECM) process is commonly used for material removal from materials which pose great difficulties for conventional machining processes. Complex shapes can also be easily machined by employing electro chemical machining. The common applications of Electro chemical machining are- machining fuel injection system components, aerospace components, dies, moulds etc. Very fewer studies have been published on electro chemical machining of stainless steel. An experimental study carried out using 2^4 factorial design and ANOVA for material removal rate of ECM on stainless steel, is presented in this paper. All the experiments are carried out on a newly developed set-up. It has been observed that the material removal rate increases with increase in voltage, feed rate and electrolyte pressure. The electrolytic flow diameter, in studied range has a small effect on material removal rate (MRR) as compared to other three factors

Key words: - ECM, New developed set up, Material SS200,MRR, 2^k factorial DOE, ANOVA.

Introduction:-

Electro chemical machining process is commonly used for material removal from materials which pose great difficulties for conventional machining processes. Complex shapes can also be easily machined by employing electro chemical machining. The ECM is used to machine a material which is electrically conductive and hard such as nickel based alloys, tool steel, super alloys, stainless steel etc. The common applications of Electro chemical machining are- machining fuel injection system components, aerospace components, dies, moulds etc. [1]. It has wider use because machining takes place without disturbing metallurgical properties of the component and gives appreciable surface finish. ECM process does not change material property and does not introduce any transformation as less heat is produced during machining.ECM is used because of its major advantages like no tool wear, no thermal stresses, unaffected by hardness of the material and good productivity.

The electro chemical machining is a process of material removal by anodic dissolution under controlled conditions. The process is based on faraday's law of electrolysis. The negative terminal is connected to tool and positive terminal is connected to a work piece. Both tool and work piece are placed inside the machining chamber with a small gap between them known as inter electrode gap (IEG). Electrolyte is electrically conductive liquid passed through IEG to complete electric circuit.

Anodic dissolution is controlled by proper selection of set of parameters such as voltage, type of electrolyte and its concentration, gap between two electrodes (IEG) and flow of electrolyte[2]. During the machining, tool movement towards the work piece plays an important role, the shape and surface finish of the tool is also equally important as a mirror image of a tool is generated on the surface of the work piece.

The effect of variation of process parameters on super duplex stainless material(SDSS) material was studied by D. Sarvanan et al [4]. Voltage (8, 9, 10 V), Electrolyte concentration (0.40, 0.45, 0.50 mol/lit), current (0.6, 0.8, 1 A), duty cycle (33.33, 50, 66.6 %), frequency (30, 40, 50 Hz) were the parameters studied in three levels. It is reported that when the concentration of electrolyte is 0.50mol/lit, voltage 9V, current 0.6A, duty cycle 66.6% and frequency 30Hz the material removal rate is highest. The duty cycle is the most contributing factor for max MRR.

D Chakradhar et al [5] studied Machining of EN31 material by varying the parameters in three levels. Voltage (10, 15, 20V), electrolyte concentration (10, 15, 20%), feed rate (0.1, 0.21, 0.32 mm/min). it is reported that the MRR is high when the input parameters are set as electrolyte voltage (20V), concentration (10%), and feed rate (0.32 mm/min). Feed rate is the most contributing factor for max. MRR

S. S. Uttarwar et al [6] have reported results of experiments on machining of SS AISI 304 material by varying the process parameters. Voltage (10, 14, 18, 20V), concentration (125,150, 175grm/lit), current (100, 125, 150, 175A), feed rete (0.1, 0.2, 0.3, 0.4 mm/min), electrolyte flow (4, 5, 6, 7 lit/min), pressure (3.4, 3.6, 3.7, 3.8 kg/cm^2) are processing parameters and levels. Optimum level to get the maximum MRR are voltage-(18V), concentration (150 gram/lit), current-175A, feed rate (0.3 mm/min), flow rate (5 lit/min), pressure (3.8kg/cm^2). It was observed that MRR was considerably affected by variation in current.

Dr. I. K. Chopade et al [7] studied practically about the effect of voltage on MRR of stainless steel material. Voltage applied during machining are 20, 30, 35, 40, 45 V and inter electrode gap is 1mm. Machining across 45V gives a high material removal rate.

This study is carried out to find effect of variation of voltage, feed rate, electrolyte pressure and electrolyte flow diameter on material removal rate of drilling on SS-200.

Working principle:-

ECM removes the material under controlled anodic dissolution in the electrolyte. The dissolution starts, when the current flows between tool (cathode) and work piece (anode) through electrolyte. On the basis of Faraday's law of electrolysis, the materials get removed (dissolved) from the work piece. Faraday's two laws govern the electrolysis process [2,3]

1. The amount of chemical change produced by an electric current, that is, the amount of any material removed, is proportional to the quantity of electricity passed [2,3]
2. The amounts of different substances dissolved by the same quantity of electricity are proportional to their chemical equivalent weights [2,3]

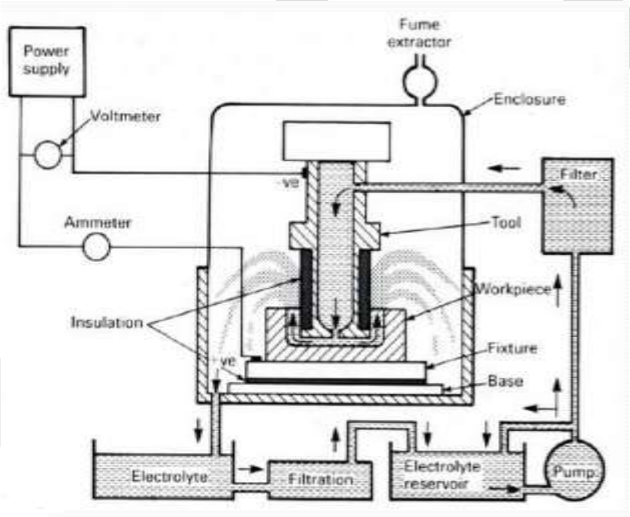


Figure1: Schematic set-up of ECM [8]

During the electro chemical machining, as potential difference is applied across the electrodes. The electrolyte and water undergoes ionic dissociation and different chemical reactions take place, ultimately removing some metal from anode surface. Let us consider a work piece of ferrous material which contains lower percentage of carbon and Sodium chloride is used as an electrolyte, when the potential difference is applied between the work piece and tool

$$NaCl \leftrightarrow Na^{+} + Cl^{-}$$

$$H_2O \leftrightarrow H^{+} + (OH)^{-}$$

The positively charged ions get attracted (move) towards the tool ad negatively charged ions move towards the work piece, Thus the hydrogen ions will take away electrons from the cathode (tool) and from hydrogen gas as:

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

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 $FeCl_2$ 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.There is no coating on the tool, only hydrogen gas evolves at the tool or cathode [9,12].

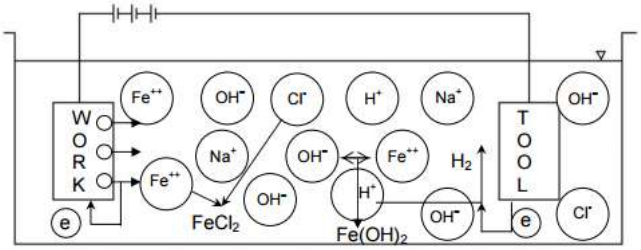
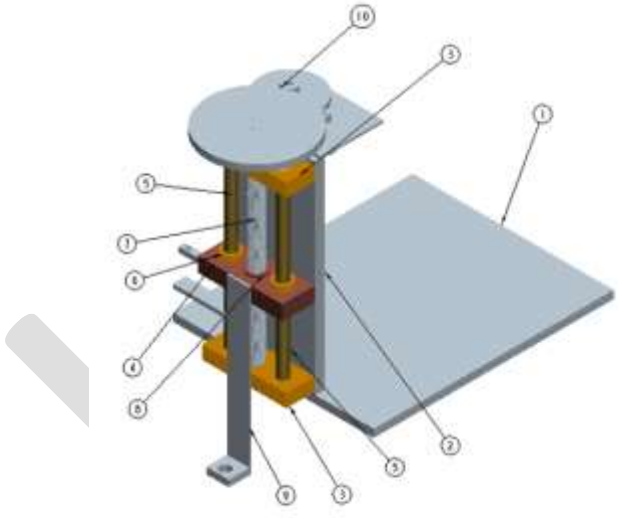
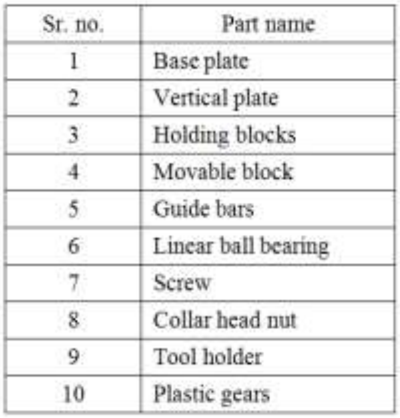


Figure 2: Representation of chemical reaction in ECM [9]

Experimental set-up:-

The literature review suggested that the process parameters which affect the response of system such as voltage, feed rate, pressure, flow rate, inter electrode gap, current density, concentration of electrolyte and type of electrolyte need to be controlled for good performance of the process. So we need an arrangement to vary these parameters for studying the performance of process and effect of these parameters. The parameters such as voltage, electrolyte flow rate, and electrolyte pressure, maximum current are to be set before the process and other parameters such as feed rate, inter electrode gap can be varied during the process. This was taken care of while developing the set-up. First 3D CAD model of a set-up was made by using PRO-E 5.0 software. This 3D model gives a visual idea about the set-up. An ECM set up is a combination of hydraulic, electrical and mechanical system. Hydraulic system takes care of the electrolyte flow rate. Electrical system takes care of the voltage and tool feed rate, and mechanical system actually holds the tool vertically and it moves linearly up and down. Mechanical system was made by assembling the various bought out components and those made in the workshop. For better look aesthetics, all machined components were blackodised.





Sr. no.	Part name
1	Base plate
2	Vertical plate
3	Holding blocks
4	Movable block
5	Guide bars
6	Linear ball bearing
7	Screw
8	Collar head nut
9	Tool holder
10	Plastic gears

Figure 3: 3D model of new tool movement mechanism in the ECM set-up

Process parameters:-

During the electrochemical machining, the material from the work piece is removed by controlling the various parameters. The parameters have some advantages and disadvantages under different condition (Value), so to do the accurate and precise machining we have to take care of the parameters. The material from the work piece is removed by the anodic dissolution. Due to the electro motive force (EMF) the atoms of the work piece try to move away [2]. This process goes on continuously & finally mirror image of the tool (cathode) is created on the work-piece. The rate of machining under ECM totally depends on the parameters such as electrolyte, flow rate of an electrolyte, voltage, temperature of electrolyte etc. This study was carried out for four parameters viz. Voltage, feed rate, electrolyte pressure, internal Diameter of tool to study their effect on material removal rate.

Electrolyte:-

Electrolyte plays an important role in ECM. Electrolyte fills the inter electrode gap and complete the electric circuit for the current to flow form the work piece to tool. It generates ions to causes the material from the work piece to be removed and take away the removed material from the machining area in the form of sludge. It also has a capacity to sustain the chemical reactions. Electrolyte cool the machining area by carrying away the heat generated during electrolysis.
Two types of electrolytes are commonly used for machining of steels - one is sodium chloride and other sodium nitrate. Both electrolytes have their own advantages and disadvantages over each other. The selection depends on the work piece and tool material and the output required. So it is important to select a proper electrolyte and its concentration [2].

Voltage:-

A constant voltage is supplied across the two electrodes (anode and cathode). Higher voltage removes the material at higher rate because of high current density. The high current density promotes rapid generation of metal hydroxides and gas bubbles in the small spacing between electrodes. These become a barrier for continuation of electrolyzing current [10]. Better performance is observed when the voltage and current is constant throughout machining. Current density decreases as the inter electrode gap increase due to removal of material, requiring higher voltage to maintain the current density, the current density is maintained by advancing the tool towards the work piece. Normally the power supply is chosen to provide constant voltage.

Flow rate:-

Sufficient flow of electrolyte is required during machining to keep the machining area free from the sludge and removal of the hydrogen gas bubbles from the tool area, if the flow rate is not sufficient there will be the chance of short circuit and heat generation.

Tool feed rate:-

To get a maximum material removal rate and good surface finish, we need to keep a constant gap between two electrodes. It is possible when the cathode (tool) advances towards the anode (work) at the same rate at which the material is removed [10].

Inter electrode gap:-

Under constant voltage DC supply, if the IEG is less, current density is high because resistance during current flow is less. So material removal rate is high and if the IEG is more the current density is low (Normally IEG is 0.5mm or less) [11]. In actual machining conditions the IEG is not constant as the material removal is different at different spots on the surface, in automatic processes the IEG is kept nearly constant by adjusting the feed rate according to current value, through servo mechanisms.

Electrolyte concentration:-

The electrolyte is flowing through the gap and carries the current between the electrodes and through that it removes the material from the work piece. Concentration of the electrolyte is very important parameter in the ECM process. The process performance is largely affected by the concentration of an electrolyte. The electrolyte concentration is given as ‘the weight of the electrolyte material ($NaNO_3$) in one liter of solution’. e.g. 200 gram/ liter. Number of ions present in the electrolyte is proportional to concentration of the electrolyte. So higher concentration of electrolyte will allow more current to pass through because it has more number of ions and removes the material at faster rate but it may cause clogging of electrolyte flow system and poor surface finish. Low concentrated electrolyte removes the material at slow rate and gives good surface finish [10]

Tool and work piece:-

Tool (cathode) is made up of copper material and stainless steel is a work piece (anode) material. The specimen composition was tested by optical emission spectroscopy. Chemical composition of stainless steel material is given below:

Sample	Chemical composition %								
	C	Mn	Si	S	P	Cr	Ni	Cu	Mo
SS	0.067	8.0	0.28	0.010	0.040	15.38	0.22	2.77	0.013

1. Electrolyte flow diameter (1.5mm) 2.Electrolyte flow diameter (2mm)

Figure 4: Tool electrode

Experimentation:-

The experimentation was carried out on the setup described above, a power supply having maximum 20A current capacity for 0-30V DC was used. Solution of NaNO$_3$in water is used as electrolyte. Electrolyte is stored in a tank and is pumped to the machining area. Pressure gauge is placed in pipe section to measure an inlet pressure and also the bypass arrangement is made for varying the electrolyte flow and pressure. Tool is made up of copper material. The electrolyte is passed through the electrode under working pressure. The figure shows the set-up arrangement.

1.DC power supply, 2.feed control circuit, 3.electrolyte tank, 4.gear train, 5.linear vertical slide, 6.dial gauge, 7.machining chamber, 8.bypass valve, 9.flow control valve, 10.tool holder, 11.pressure gauge

Figure 4: Newly developed set-up of ECM

Tool is held inside a tool holder, electrolyte is supplied at the machining area, through a central hole. Insulation is applied on the circumference of a tool except 0.1mm at the front end of tool and the face of tool. The work piece is clamped inside the vice at the required position. The IEG of 0.3mm is set. Dial gauge is attached at the tool holder to measure the inter electrode gap and the tool movement (tool feed).The pressure gauge and the voltage knob on power supply are set to the values as per the DOE.

Experimental design:-

Experiments were scheduled using design of experiment (DOE). DOE gives the combination of parameters for the experimentation and so the parameters are easily varied as per convenience during experimentation. The experiments are planned using 2^k factorial design for four parameters(k=4). It gives all possible combinations of parameters.

Number of experiments=2^k

No. of experiments= $2^4 = 16$

Following table shows the parameters and its levels:

TABLE1: Parameters and its levels

Parameters	Unit	Nomenclature	Low(-1)	High(+1)
Voltage	V	A	12	16
Feed rate	mm /min	D	0.4	0.6
Pressure	Bar	C	0.5	1
Electrolyte Flow diameter	mm	D	1.5	2

Following table shows the all possible combination of parameters and its response (MRR).

TABLE2: Experimentations and its results

Voltage (A)	Feed rate (B)	Pressure (C)	Electrolyte Flow diameter (D)	Material removal rate (gram/min)
(-1)	(-1)	(-1)	(-1)	0.085
(-1)	(-1)	(-1)	(+1)	0.094
(-1)	(-1)	(+1)	(-1)	0.098
(-1)	(-1)	(+1)	(+1)	0.105
(-1)	(+1)	(-1)	(-1)	0.131
(-1)	(+1)	(-1)	(+1)	0.135
(-1)	(+1)	(+1)	(-1)	0.148
(-1)	(+1)	(+1)	(+1)	0.155
(+1)	(-1)	(-1)	(-1)	0.125
(+1)	(-1)	(-1)	(+1)	0.131
(+1)	(-1)	(+1)	(-1)	0.135
(+1)	(-1)	(+1)	(+1)	0.141
(+1)	(+1)	(-1)	(-1)	0.165
(+1)	(+1)	(-1)	(+1)	0.171
(+1)	(+1)	(+1)	(-1)	0.18
(+1)	(+1)	(+1)	(+1)	0.195

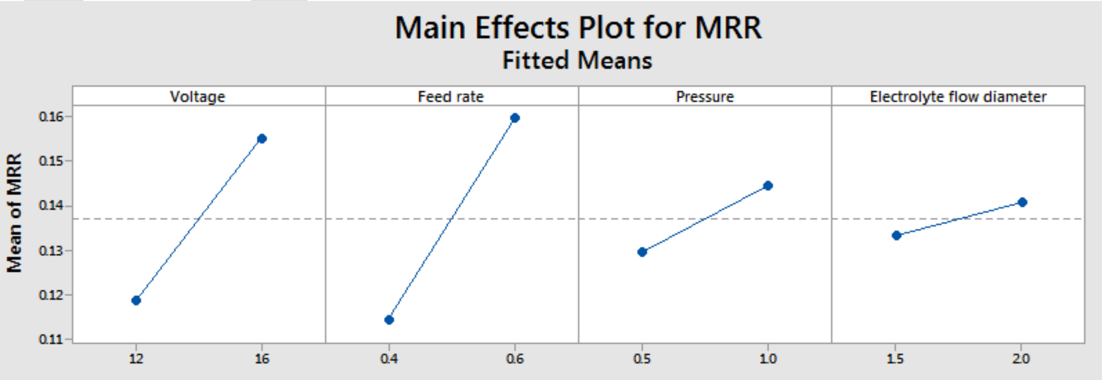


Figure 5: Main effect plot for MRR.

Analysis of experiments:-

Analysis of variance (ANOVA)

Degree of freedom (DOF) = (number of levels -1). Therefore DOF for each factor =1(2-1)

F-test (calculation for F value) $F_0 = SS_A/V_A \,/\, SS_E/V_E = MS_A/MS_E$

Where, $SS_{A=}$ sum of square due to A.

SS_E= sum of square due to error.

V_A=DOF for factor A.

V_E=DOF for error.

MS_A=mean square for A.

MS_E=mean square for error.

Ex. F_0 for A= 0.005329/(4.55*10^(-6))=1171.20

% of Contribution of significant factors is shown at last column of ANOVA table.

% of contribution of A= $(SS_A/(\sum SS))*100$

Ex. % contribution of factor A= (0.005329/0.0149358)*100=35.68%

TABLE 3: Results of ANOVA

SR. NO	FACTORS	SUM OF SQUARE	DEGREE OF FREEDOM	VARIANCE OF MEAN SQUARE	F0	Contribution (%)
1	A	0.005329	1	0.005329	1171.209	35.67949
2	B	0.0083723	1	0.00837225	1840.055	56.0551
3	C	0.0009	1	0.0009	197.8022	6.025811
4	D	0.000225	1	0.000225	49.45055	1.506453
5	BC	6.4E-05	1	6.4E-05	14.06593	0.428502
6	Pooled error	4.55E-05	10	4.55E-06		0.304638
	Total	0.0149358	15			100

Degree of freedom for numerator=1

Degree of freedom for denominator=10

Therefore consulting F-Distribution table, for 95% confidence level, we find that $F_{0.05,\,1,\,10}$= 4.965[13]. F_0 value for the factors A, B.C, D, BC is given in the above table. If the F_0 value of give factors is greater than the critical F- value (F_0>F) then the factors are significant.

Results and discussion:-

AS per the DOE all the experiments are carried out and observations are recorded as given in table above. Normal plot of the standardized effect gives the significant factors by using Minitab 17.F-test gives a F_0 value for the significant factors. All the F_0 are greater than F ($F_{0.05,\,1,\,10}$=4.965). The feed rate has big contribution for getting the maximum MRR. The effect of the parameters in order of significance is feed rate then voltage, pressure, electrolyte flow diameter and last is feed rate-pressure interaction. MRR increases as the voltage and feed rate increases. If the applied voltage increases, the machining current in the IEG increases, which leads to increase in MRR. High feed rate reduces the IEG. If IEG is small then current density is high. This effect causes rapid anodic dissolution which increases MRR.

ANOVA table shows the % contribution of all the significant factors. Voltage (35.68%), feed rate (56.0551%), pressure (6.03%), electrolyte flow diameter (1.5064%)and final feed rate-pressure (0.428502%).

Conclusion:-

This experimentation study was performed to investigate the effect of process parameters on material removal rate by using electrochemical machining of SS200 material. The material removal rate of SS200 is increased significantly by increasing feed rate, voltage and electrolyte pressure. The Electrolyte flow diameter, feed rate-pressure interactions have less effect on the response compare to feed rate, voltage and pressure. Maximum material was removed when the input parameters set as feed rate (0.6 mm), voltage (16V), pressure (1 bar) and electrolyte flow diameter (2 mm).

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