UNIT-3

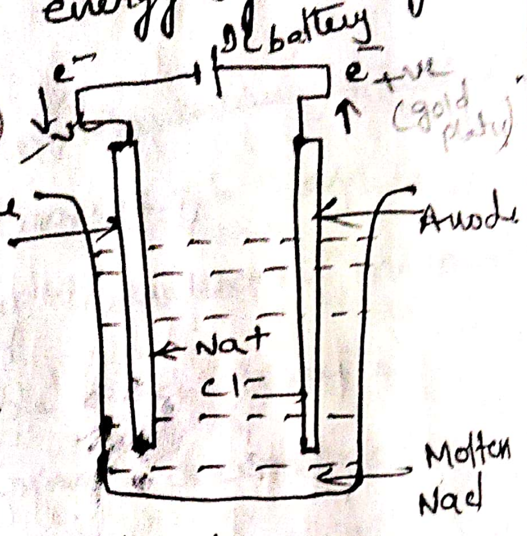
Electro Chemical Machining

Electrolysis

→ Electrical Energy is transported through metals by conduction of ~~and~~ electric charges from one place to another.

→ As opposed to the metallic conduction, where only electrons are the charge carriers, salt solutions conduct electrical energy by the migration of ions in the medium

→ fig shows an electrolytic cell in which DC battery sends electric current through the molten sodium chloride salt.



→ Electrons from the battery enters at the the cathode and when the circuit complete, they leave at the anode returning to the battery.

→ Sodium ions (Na^+) combine with the electrons available at the cathode, and produce sodium metal which accumulates at the cathode region as

$$Na^+ + e^- \rightarrow Na$$

→ Sodium ions are reduced at the cathode.

→ At the same time, chloride ions migrate towards the anode and are oxidized to chlorine as

$$Cl^- \rightarrow \frac{1}{2}Cl_2 + e^-$$

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→ The electrons are consumed at the cathode by the positive ions and are released by the negative ions.

~~Electro chemical Machining (ECM)~~

~~Principle:~~

~~It works on the principle of Faraday's laws of electrolysis.~~

Electro chemical Machining (ECM)

Principle

→ The feature of electrolysis is that the electrical energy is used to produce a chemical reaction, therefore, the machining process based on this principle is known as electro chemical Machining. The process works on the principle of Faraday's laws of electrolysis.

→ In ECM, small electric DC potential (5-25V) is applied across the two electrodes i.e., cathode and anode (anode is work and cathode is tool) immersed in electrolyte.

→ The transfer of electrons b/w the ions and the electrodes completes the electrical circuit.

→ The metal is detached atom by atom, from the anode surface and appears in the electrolyte as positive ions.

→ The detached metal appears as precipitated solid of metal hydroxide.

→ During electrolysis of water, its molecules gain electrons from cathode so that they seperate into free hydrogen gas and hydroxyl ions.

$$2H_2O + 2e^- \rightarrow H_2\uparrow + 2OH^-$$

As the anode dissolves, negatively charged hydroxyl ions are electrically balanced by positively charged metal ions entering in to the electrolyte.

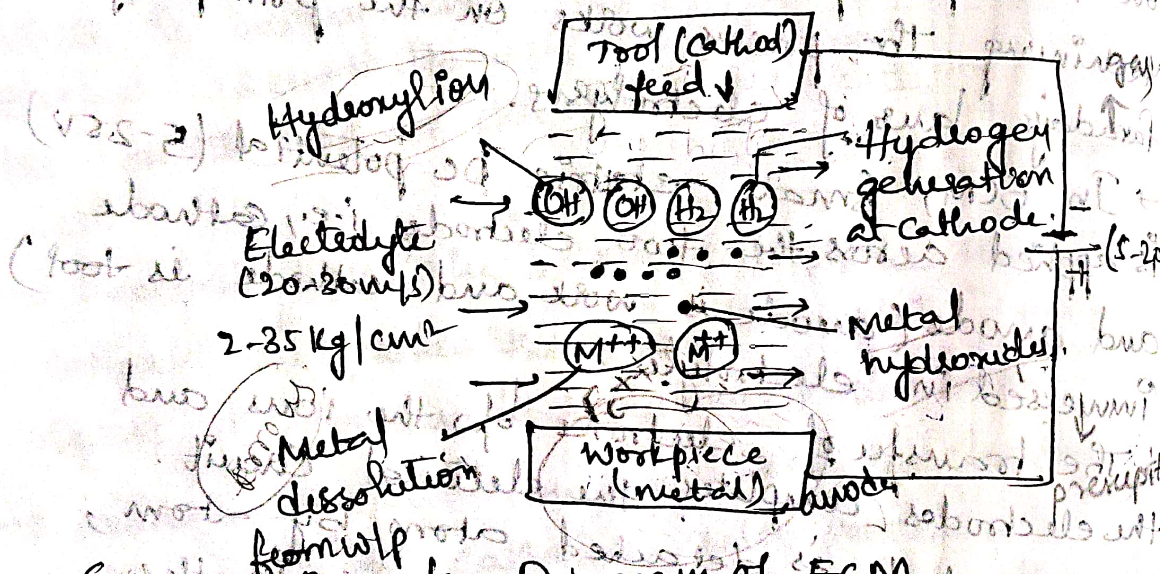
$$Fe - 2e^- \longrightarrow 2Fe^{2+}$$

$$Fe^{2+} + 2(OH)^- \longrightarrow Fe(OH)_2$$

Metal ions do not remain as ions in the solution when neutral electrolytes are used, but combine with the hydroxyl ions to form metal hydroxides.

→ These hydroxides are insoluble in water hence they appear as solid precipitates and no longer affect the electrochemical reaction.

$$Fe + 2H_2O \longrightarrow Fe(OH)_2 + H_2 \uparrow$$



~~Schematic~~ Principle Diagram of ECM

Ferrous hydroxides may further react with water and oxygen to form ferric hydroxide

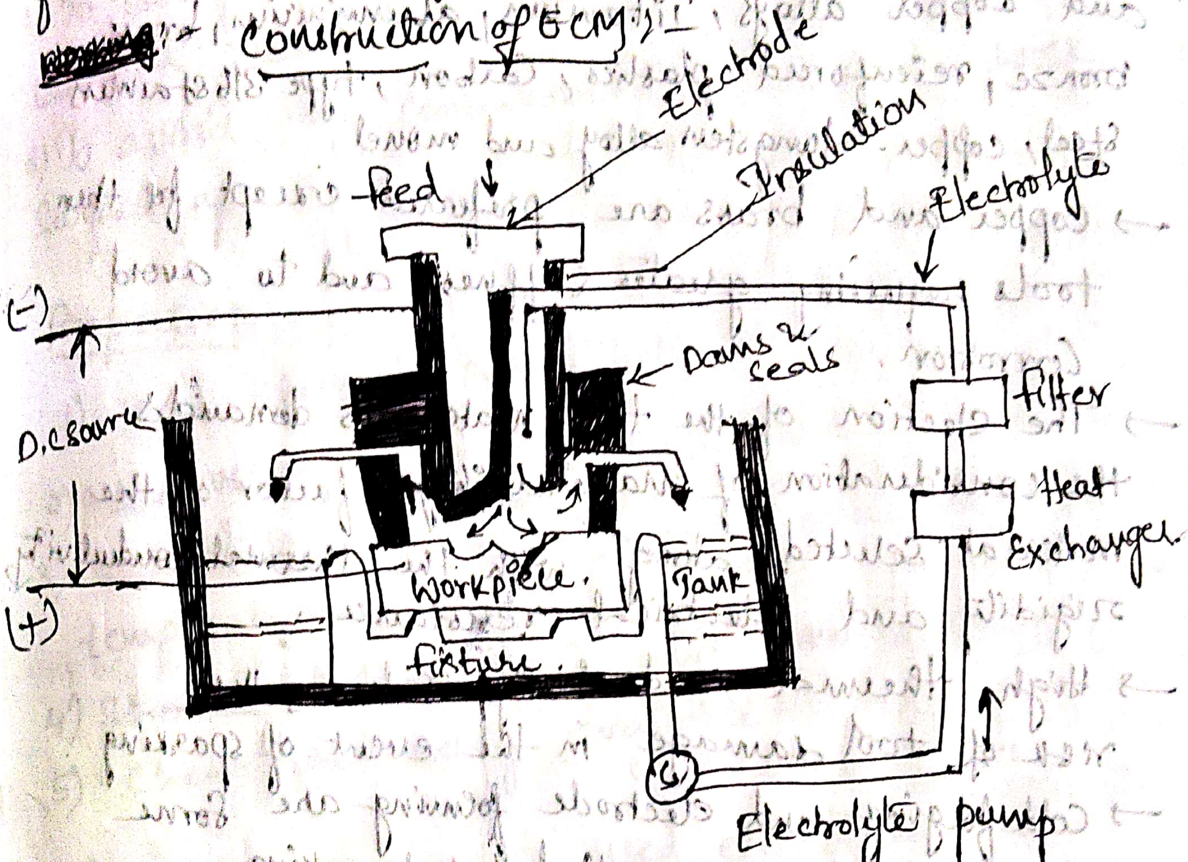
$$4Fe(OH)_2 + 2H_2O + O_2 \longrightarrow 4Fe(OH)_3$$

Smaller the interelectrode gap (IEG), greater will be the current flow because resistance decreases and higher will be the rate of metal removal from the anode.

→ High current density, in the small spacing (usually about 0.5mm or less) promotes rapid generation of reaction products, hydroxide solids and gas bubbles.

→ These reactions products act as a barrier to the flow of electrolyzing current and these effect is minimized by supplying the electrolyte at a pressure of 2 to 85 kg/cm², leading to the electrolyte flow velocity as high as 20-30 m/s.

Construction of ECM :-



Equipments and their elements :-

The different elements that are present in an Electro chemical Machining equipment are.

1) power source
2) Electrolyte
3) electrodes

4) The filters and settling tanks.
5) Tool feed system.

1) Electrodes :-

Cathode tools :-

→ The accuracy of the tool directly influence workpiece accuracy

→ Poor surface finish of the tool will produce a poor surface on the part.

→ Tool electrodes are made commonly of copper and and copper alloys, Titanium, aluminium, brass, bronze, reinforced plastics, Carbon, type 316 stainless steel, copper - tungsten alloy and monel

→ Copper and brass are preferred except for thin tools requiring greater stiffness and to avoid corrosion.

→ The slection of the tool materials demands the consideration of machinability factor of the material selected along with the thermal conductivity rigidity and electrical resistance.

→ High thermal conductivity reduces the risk of tool damage in the event of sparking.

→ Cold forging and electrode forming are some of the advantageous method of tool making.

Anode workpiece :-

→ There is no restriction for the workpiece material to be machined by ECM process, except that it must be good conductor of electricity.

2) Electrolyte:-

The main function of the electrolyte in the ECM process are

a) for completing the electric circuit b/w the tool and the w/p and to allow the reaction to proceed efficiently.

b) To remove the products of machining from the cutting region.

c) To carry away the heat generated during the chemical reaction.

d) To avoid ion concentration at the tool - work surface gap.

Properties:-

1) High thermal conductivity
2) Low viscosity and high specific heat
3) Should be chemically stable even at high temperatures.
4) Should be non-toxic and non corrosive.
5) Cheap and easily available.

→ The most commonly used electrolytes are 15-20% Sodium Chloride in water, but the use is limited because of its corrosiveness.

→ Sodium nitrate is also used as electrolyte but it is expensive than sodium chloride.

→ Other alkaline chemicals used as electrolyte are potassium nitrate, sodium sulphate, sodium chromate, sodium hydroxide and potassium chloride.

→ Mixture of two or more of the chemicals can also be used as an electrolyte.

→ weak acids ~~and~~ used as an electrolyte found to produce good surface finish.

The improper selection of an electrolyte would result in

1) Lower machining rate
2) Over cuts and stray cutting.
3) Etching at grain boundaries of work material which reduce the fatigue strength of the machined parts.

→ All electrolytes must be cooled to remove the heat due to reaction and to maintain the temperature, otherwise the electrical conductivity of the electrolyte will be affected.

→ The increase in temperature decreases the machining voltage which is required to maintain current density.

→ Sludging electrolytes produce insoluble hydroxide and hydrated oxides.

→ A proper electrolyte selected should not produce sludge not more than 2% of its weight.

3) <u>power supply unit</u>:

→ ECM process requires low DC voltage from 5 to 15 volts normally, but in some cases it may go as high as 30V.

→ If there is A.C supply it should be converted into DC supply using rectifiers.

→ Current rating from 100A to 40,000A is used.

→ The voltage must be precisely controlled.

because it influences the equilibrium of the machining gap and accuracy of the work.

→ The use of silicon controlled rectifiers is very common for voltage control in ECM.

4) Filtering and settling tanks:-

→ Filters are used to clean the used electrolyte of the foreign materials like particles of plastic, grit, metal paper etc so that the electrolyte could be reused.

→ The particles of machining are very small in size which are found to be difficult to filter.

→ Filters made of steel or monel mesh are mostly suitable for the ECM process.

→ Normally wire mesh of 75 mm size is used since the operating gap is normally 0.25 mm or more.

→ The filter have to be cleaned for every 30 hours of filtration.

four methods are generally used to remove this

1) Running the system until it is contaminated completely and replace it.

2) Centrifugal seperation

3) Sedimentation.

4) use of a clarifiers

→ The first method is commonly practised, but for small batches of parts.

→ The 2nd method is expensive one

→ The 3rd method is a very slow process which needs more floor space

→ The 4th method is an accelerated setting system.

→ A settling tank must be large because of the very slow settling rate of the products of machining & such tanks are usually the size of swimming pools.

→ Their large size acts as an excellent sink making electrolyte temperature control easier.

→ The tank for storing the electrolyte is divided into clean and dirty compartment.

→ The electrolyte in the machine flows into the dirty tank and is sent to the centrifuge or clarifier.

→ The cleaned electrolyte ~~may be also~~ flows into the clean side of the tank.

→ The high pressure pumps delivers the clean electrolyte from the clean side of the tank to the machine, through a pressure reducing valve, a safety filter and flow meter.

5) <u>Tool feed system</u> :-

→ The tool work gap plays a vital role on the machining rate of the work material.

→ Under equilibrium conditions, the tool feed rate is directly proportional to the current density.

→ If the feed rate is increased, the electrical resistance of the circuit reduces and allow more current to flow, increasing the machining rate.

→ The tool does not wear away during machining.

→ It is a requirement that the tool must be fed into the work at a constant rate which depends upon how fast it is required to remove the metal.

Working

→ The workpiece is assembled in the fixture and the tool is brought close to the workpiece.

→ The tool and workpiece is immersed in a suitable electrolyte, after that a potential difference is applied across the workpiece which is a node and tool which is cathode the removal of material starts and ~~The material is removed~~

→ The tool feed system advances the tool towards the workpiece and always keeps a required gap in between them the material from the workpiece comes out as positive ions and combine with the ions present in the electrolyte and precipitates as sludge

→ Hydrogen gas is liberated at the cathode during the machining process.

→ Since the dissociation of the material from the workpiece takes place at atomic level so it gives excellent surface finish.

→ The sludge from the tank is taken out and seperated from the electrolyte the electrolyte after fitteration again transported to the tank for the machining process

→ ECM in comparison with purely Chemical methods of machining offers the possibility of much greater rates of metal removal and more precise control of the shape.

→ It is suitable for machining tough, high temperature materials and alloys, the use of which characterizes the aerospace industries

→ The aerospace Industries are using electrochemical machining techniques extensively to machine very hard materials and for providing complex shapes to these hard materials

→ ECM can also be used for machining ~~con~~ conventional materials also.

The engg. materials that can be machined by ECM process with suitable electrolytes are

1) Iron based alloys (Hardened die steels)
2) Titanium
3) Tungsten
4) Tungsten Carbide
5) Nickel based alloys
6) Stainless steel.

Advantages :-

1) Metal is removed rapidly
2) complex shaped workpieces can be machined economically
3) Stress free surface can be Produced
4) No tool wear
5) operations such as cutting, sawing, machining & contour milling, grinding, deburring and polishing etc can be done.
6) It gives good surface finish, better corrosion resistance and better accuracy.

Disadvantages :-

1) Large floor space and high capital cost is required.
2) Difficult tool design.
3) power consumption is high.
4) Machining limited to electrically conductive materials only.
5) High tooling and initial cost
6) Not economical for small lots
7) It cannot produce sharp corners and edges

Applications

1) Used for machining difficult to machine materials and complex shaped parts.
2) Blind complex cavities, curved surfaces, through cutting and large through cavities can be machined
3) Drilling of long and slender holes can be achieved. Holes of dia. 0.025 mm can be produced.

Depth of holes can be as deep as 600mm.

4) Hole shapes other than circular ones can be drilled

5) used for cavity sinking of gas turbine blades and other components

6) Operations such as sawing, honing, deburring and turning can be done.

7) Wire cutting can also be acheived.

8) Surfacing can also be done, where the tool surface is slightly curved at bottom face

9) To extract test blocks from forging, castings and rolled shapes.

10) Thin wall mechanical slotting of the collets can be produced.

11) Hollow shafts can be machined easily.

12) Die sinking, profiling, multi hole drilling, broaching are some of the industrial applications.

Metal removal rate in ECM :-

The rate of dissolution (material removed) can be analysed from the basic fundamental of electrochemistry given by Faradays laws.

1) I law states that "The amount of chemical changes W produced (i.e., dissolved or deposited) is proportional to the amount of charge Q passed through the electrolyte" i.e.,

$$W \propto Q \quad \text{——} \quad (1)$$

2) II law proposes that the amount of change produced in the material is proportional to its electrochemical equivalent, ECE of the material i.e.,

$$W \propto ECE$$

$$\text{but } ECE = \frac{M}{V} \quad \text{——} \quad (2)$$

where M = atomic weight,
V = valency.

from the two laws it can be written

$$W = \frac{1}{F}(ECE) \cdot Q$$

$$= \frac{1}{F}\frac{M}{V} Q \quad \text{——} \quad (3)$$

$$W = \left(\frac{1}{F}\frac{M}{V}\right) It \quad \text{——} \quad (4)$$

Where, F is the faradays constant = 96500 coulombs.
= 26.8 amp-hr.

Q the charge (coulomb)
I the current (ampere)
t the dissolution period.

Equ (4) gives the idea about the rate of dissolution of a single elemental material

<u>Dissolution of an alloy:-</u>

Generally an engineering material is in the form of an alloy consisting of different elements.

So to find out the rate of dissolution, one must consider each element seperately and combine them for the whole alloys.

Let us consider the alloy consisting of

$1 - n$ = number of elements

$M_1 -- M_n$ = atomic weights of individual elements

$V_1 --- V_n$ = Valency of the respective elements

$X_1 -- X_n$ = % of the element present in the alloy

Now, if ρ is the density of the alloy

V_a is the volume that goes in to soln in a given time t,

Then the weight W of the first element present in the alloy is given by

$$W_1 = \frac{V_a \rho X_1}{100}$$

lly

$$W_2 = \frac{V_a \rho X_2}{100}$$

$$W_n = \frac{V_a \rho X_n}{100}$$

the charge $(Q_1 - Q_n)$ taken by each element present in the alloy can be given by Eqn (3)

$$Q_1 = \frac{W_1 f v_1}{M_1} = \frac{V_a \rho F}{100} \frac{v_1 x_1}{M_1}$$

IIly

$$Q_2 = \frac{W_2 f v_2}{M_2} = \frac{V_a \rho F}{100} \frac{v_2 x_2}{M_2}$$

$$Q_n = \frac{W_n f v_n}{M_n} = \frac{V_a \rho F}{100} \frac{v_n x_n}{M_n}.$$

Now, the total charge required for removing all the elements from the alloy will be

$$Q_{total} = Q_1 + Q_2 + \cdots + Q_n \quad \text{--- (5)}$$

$$Q_{total} = \frac{V_a \rho F}{100} \left[\frac{x_1 v_1}{M_1} + \frac{x_2 v_2}{M_2} + \cdots + \frac{x_n v_n}{M_n} \right]$$

$$Q_{total} = \frac{V_a \rho F}{100} \sum_{i=1}^{i=n} \frac{x_i v_i}{M_i} \quad \text{--- (6)}$$

Hence Volumetric removal rate V_m per unit material charge is given by

$$V_m = \frac{V_a}{Q_{total}} = \frac{100}{\rho F} \frac{1}{\sum_{i=1}^{i=n} \frac{x_i v_i}{M_i}} \quad \text{--- (7)}$$

If current I flows for time t sec, then from eqn (6)

$$Q_{total} = It = \frac{V_a \rho F}{100} \sum_{i=1}^{i=n} \frac{x_i v_i}{M_i}$$

$$MRR = \frac{V_a}{t} = \frac{V_a}{\frac{V_a PF}{100} \sum_{i=1}^{i=n} \frac{X_i V_i}{M_i}}$$

$$\boxed{MRR = \frac{100}{PF} \frac{1}{\sum_{i=1}^{i=n} \frac{X_i V_i}{M_i}}} \quad \text{—— (8)}$$

Tool design :-

→ Tool design is the main factor for the successful application of ECM process

→ The criteria for a good ECM tool are that it should be a good conductor of electricity and heat, easily machinable, resistant to chemical reactions without loosing its shape and dimension, offering resistance to the high electrolyte pressure

→ There are two major aspects of tool design in ECM

1. Determination of tool shape to machine the w/p to the desired shape of the w/p for a given machining condition.
2. Design of the tool so as to fix it in the m/c, connecting it to the power supply, arranging for an adequate supply of electrolyte b/w the tool and work surface

and insulating the tool to avoid over cutting and taper.

→ Defects in the tool such as bumps or pits will be produced in the w/p surface as a reverse image, if they are not removed.

→ The ECM tool is approximately the mirror image of the machined area of the completed part.

→ The tool dimensions are modified to allow for side over ~~cut is about to~~ and front machining gaps which range from 0.025 to 0.5 mm the side over cut is about 1.5 times the front gap.

→ The tool design involves careful emperical formulation of slope and curvature of the tool with respect to the feed direction, metal removal rates, variation in current densities, geometrical and graphical details.

Material removal rate :-

→ MRR is an important characteristic to evaluate efficiency of a non traditional machining process.

→ In ECM material removal takes place due to atomic dissolution of work material.

→ Electro chemical is given by faradays law.

I law :- states that the amt of ~~material~~ electrochemical dissolution or deposition is proportional to amount of charge passed through the electrochemical cell, which is expressed as

$$\boxed{m \propto Q} \quad \text{(1)}$$

Where m = mass of material dissolved or deposited

Q = amount of Charge passed

II law :- states that the amount of material deposited or dissolved further depends on Electrochemical equivalence (ECE) of the material that is again the ratio of the atomic weight and valency

$$m \propto ECE \propto \frac{A}{V} \quad \text{—— (2)}$$

from (1) & (2) we get, $m \propto \frac{QA}{V}$

Where F = faradays constant = 96500 coloumbs

$$\therefore m \propto \frac{itA}{V} \qquad Q = it$$

$$m = \frac{itA}{FV}$$

Where, i = current and ρ = density of material

$$MRR = \frac{\text{Volume of material removal}}{\text{time}}$$

density = $\frac{\text{mass}}{\text{vol.}}$

$$\rho = \frac{m}{V}$$

$$V = \frac{m}{\rho}$$

$$MRR = \frac{m}{t\rho}$$

$$= \frac{itA}{FVt\rho}$$

$$\boxed{\therefore MRR = \frac{iA}{F\rho V}}$$

Surface finish and accuracy of ECM:-

ECM is a process used to shape metal parts through controlled dissolution using an electrolyte and electrical current. when considering the economic aspects of ECM, both surface finish and accuracy play significant roles.

Surface finish.

→ ECM can acheive excellent s/f finishes, often. The process can produce smooth and uniform surfaces without the need for secondary finishing operations, saving time and resources.

→ Superior surface finishes can lead to reduced post processing requirements, such as polishing or grending, thereby lowering overall manufacturing costs.

→ The ability to acheive high quality surface finishes can enhance the performance and aesthetics of the final product, adding value for customers and potentially commanding premium pricing.

Accuracy:-

→ ECM is known for its high accuracy and dimensional precision. It can produce intricate shapes with tight tolerances, often without inducing mechanical stresses or distortions in the workpiece.

→ The precision offered by ECM reduces the errors or rework, leading to higher productivity and

Cost savings over time:
→ In industries where component accuracy is critical, such as aerospace and medical device manufacturing, ECM's capability to maintain tight tolerances is invaluable and can justify the initial investment in equipment and training

Economic Considerations

→ While ECM offers advantages in surface finish and accuracy, its essential to consider the overall economic viability of the process. Factors such as initial equipment costs, maintenance expenses and operating expenses (including power consumption and electrolyte replenishment) must be weighed against the benefits.

→ for high volume production runs or applications requiring complex geometries and tight tolerances, ECM's efficiency and precision can lead to significant cost savings compared to traditional machining methods

→ Economic feasibility also depends on the availability of skilled operators and engineers trained in ECM technology. Investing in training and development can enhance efficiency and maximize the return on investment!

Problems

1) In an electrochemical machining operation a square hole of dimensions 5mm x 5mm is drilled in a block of copper. The current used is 5000A, Atomic weight of copper is 63 and valency of dissolution is 1, faradays constant is 96500 coulomb. find The metal removal rate (g/s).

$i = 5000A$.

$A = 63$

$v = 1$

$F = 96500$.

$$MRR = \frac{Ai}{Fv} = \frac{63 \times 5000}{96500 \times 1} = 3.26 \text{ gm/s}.$$

2) During the ECM of iron (Atomic weight = 56, Valency = 2) at current of 1000A with 90% current efficiency the material removal rate was observed to be 0.26 cc/s. If titanium (atomic weight = 48, Valency = 3) is machined by the ECM process at the current of 2000A with 90% current efficiency, the expected material removal rate in cm/s will be how much?

$$MRR = \frac{Ai}{F\rho v}$$

$A = 56$

$v = 2$

$i = 1000 \times 0.9$

$F = 96500$.

$$0.26 = \frac{56 \times 1000 \times 0.9}{96500 \times \rho \times 2}$$

$\rho = 0.9956$

Now, expected $MRR = \dfrac{48 \times 1000 \times 0.9}{0.9956 \times 3 \times 96500}$

$= 0.30\ gm/s$

3) Calculate the MRR when copper is electrochemically machined under following conditions

$V = 18$ volt, $I = 500A$, Atomic wt $= 56$,

Valency $= 2$, $\rho = 7.8\ gm/cm^3$

Soln.

$A = 56$

$V = 18$ Volt

$I = 500A$

$\rho = 7.8\ gm/cm^2$

$v = 2$

$MRR = \dfrac{Ai}{F\rho v} = \dfrac{56 \times 500}{96500 \times 7.8 \times 2}$

$= 0.0186\ cm^3/s$

4) In a certain Electro chemical dissolution process of iron, a metal removal rate of 2 cc/min was desired. Determine the amt of Current required for the process. Assume: Atomic wt of iron, $A = 56\ gm$

Valency at which dissolution occurs, $v = 2$

$F =$

Density of iron, $\rho = 7\ gm/cc$.

Soln: Atomic wt $A = 5.6\ gm$.

$v = 2$

gram equivalent wt of iron,

$$ECE = \frac{A}{v} = \frac{56}{2} = 28.$$

Amount of iron dissolved

$$m = \frac{itA}{F\rho v}$$

Thus, $MRR = \frac{m}{t} = \frac{iA}{F\rho v}$ 1 min = 60 sec, F = 96500

$$2 = \frac{28 \times i}{96500 \times 7}$$

$$i = \frac{96500 \times 7 \times 2}{28}$$

$i =$

5) While removing material from Iron (atomic weight = 56, Valency = 2 & density = 7.8 g/cc. by ECM, MRR mass 2cc/min is desired. find the current in A for achieving this MRR.

Soln

$$MRR = \frac{Ai}{F\rho v}.$$

$$\frac{2}{60} = \frac{56 \times i}{96500 \times 7.8 \times 2}$$

(cc/sec).

then $I = 448A$.