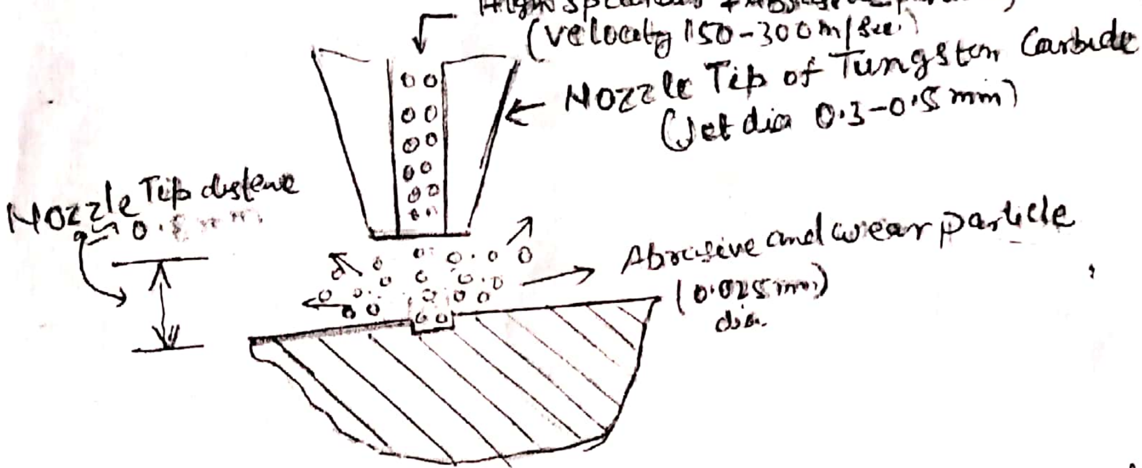
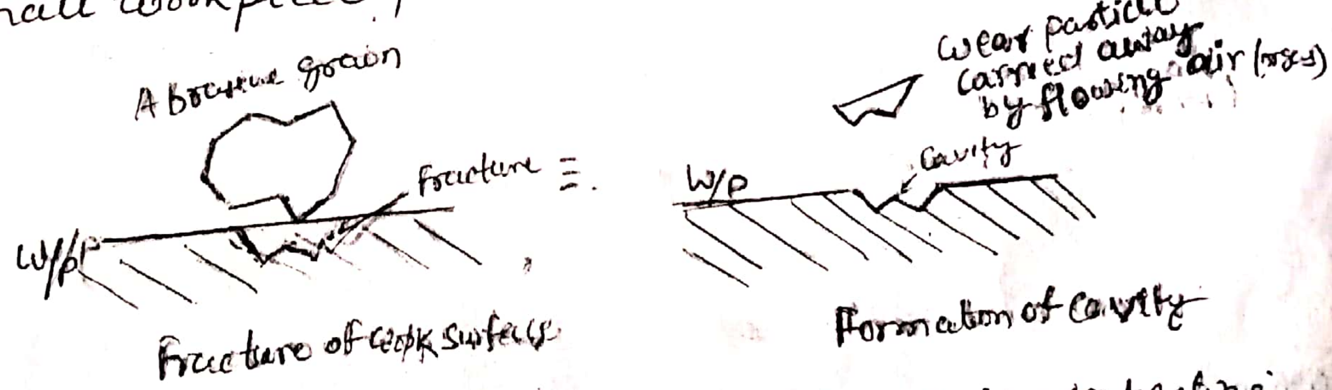
Ch.2: Non-Convention machining

1. Abrasive Jet Machining (AJM): (lec. 04 & 05)

In AJM, the material removal takes place due to the impingement of the fine abrasive particles. These abrasive particles move with a high speed stream of abrasive carried by air (or gas) at a pressure 2 to 10 bar. Material removal occurs through erosion caused by abrasive particle impacting the surface of work-piece at high speed.



When an abrasive particle impinges on the work surface at a high velocity, the impact causes a tiny brittle fracture and the following air (or gas) carries away the dislodged small workpiece particle (wear particle).



The MRR due to chipping of the work surface by the impacting abrasive particle is expressed as

$$MRR = x Z d^3 v^{3/2} \left(\frac{\rho}{12 H_w}\right)^{3/4}$$

where Z = No. of Abrasive particles impacting per unit time

d = mean diameter of abrasive grain

density of the abrasive grains

Process parameters

(i) Abrasive (Composition, Strength, Size and mass flow rate)
(ii) Gas (Composition, press. and velocity)
(iii) Nozzle (Geometry, material, distance from and inclination to the work surface)

Process characteristics : Characteristics control by process parameters

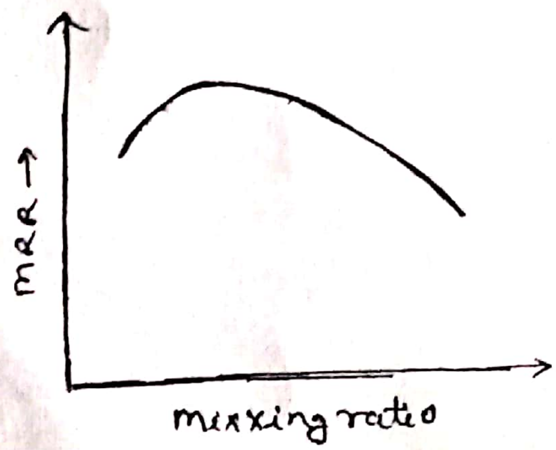
→ MRR
→ Geometry of Cut
→ the roughness of surface produced
→ Rate of nozzle wear

Abrasive:

→ mainly two type of abrasive used (i) Aluminium oxide (Al_2O_3) (preferred)
(ii) Silicon Carbide (SiC)

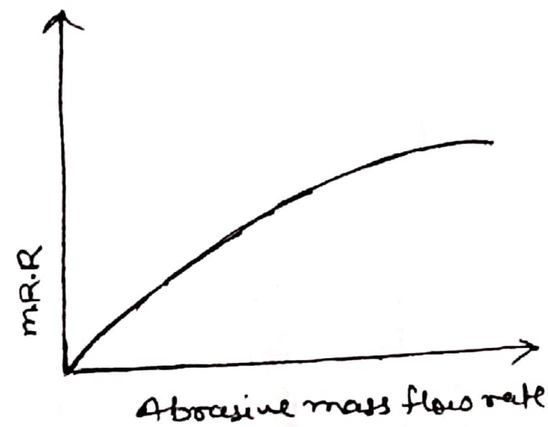
→ Generally Al_2O_3 and SiC powder with a nominal grain dia of 10-50 um are available but best Cutting is achieved when the nominal dia is betn. 15um and 20um.

MRR vs mixing ratio



When the mass fraction of abrasive in the jet (mixing ratio) increases, the MRR initially increases but with a further increase in the mixing ratio, it reaches a maxm and then drops.

MRR vs Abrasive mass flow rate



When the mass flow rate of the abrasive increases, the M.R.R also increases.

Gas

→ AJM operates at a press. of 0.2 N/mm² to 1 N/mm² i.e 2 to 10 bars

→ A high velocity Gas Stream Causes a high MRR even if the mass flow rate of the abrasive is kept Constant.

Nozzle

→ the most vital elements Controlling the process characteristics.

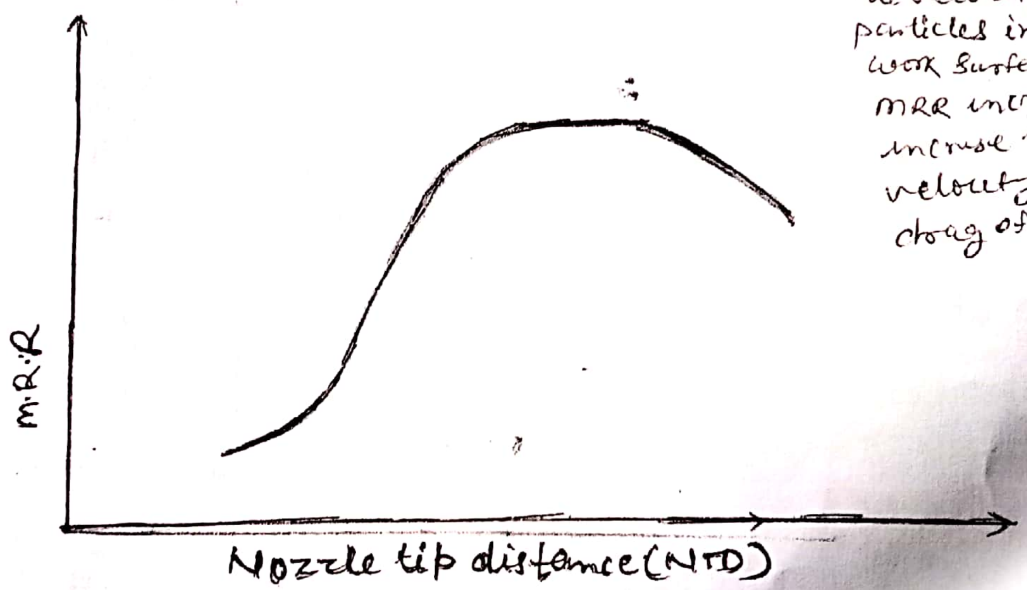
→ Nozzle made from material must be very hard to avoid any Significant wear Normally WC (Tungsten Carbide) or Sapphire is used.

→ X/sec. area of the orifice is betn 0.05 mm² and 0.2 mm², the Shape of the orifice can be either circular or rectangular.

→ WC nozzle last betn. 12 hr and 30 hrs.
Sapphire nozzle lasts for 300 hrs approximately.

→ the distance betn. the work surface and the tip of the nozzle, called nozzle tip distance (NTD)

MRR vs Nozzle tip distance (NTD)



when NTD increases then the velocity of abrasive particles impinging on the work surface increases the MRR increases, with further increase in NTD, the velocity reduces due to drag of the atmosphere.

Abrasive jet machines : Refers Books by Amitabh Ghosh, Page No. 321

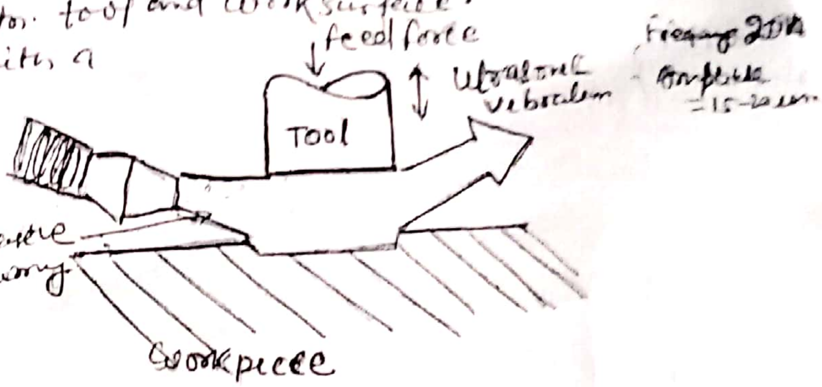
Applications :

→ materials like hard and brittle metals, alloys and non-metallic materials (e.g germanium, silicon, glass, Ceramics and mica)

→ Job application like drilling, cutting, deburring, etching, cleaning

2. Ultrasonic machining (USM)

material removal in USM process involves a tool vibrating with a very high frequency and a continuous ~~and~~ flow of an abrasive slurry in the small gap betw. tool and work surface. The tool is gradually feed with a uniform force. The impact of hard abrasive grains fracture the hard and brittle work surface, resulting in the removal of work material in the form of small wear particles which are carried way by abrasive slurry.



Mechanism of ~~abrasive~~ USM

The reasons of material removal during USM are believed to be

(i) the hammering of the abrasive particles on the work surface by the tool.

(ii) the impact of free abrasive particle on the work surface

(iii) the erosion due to cavitation.

(iv) the chemical action associated with the fluid used.

A number of researchers have tried to develop the theories to predict the characteristics of ultrasonic machining. The model proposed by M.C. Shaw is generally well-accepted. In this model, the direct impact of the tool on the grains in contact with the workpiece (which is responsible for the major portion of the material removal) is taken into consideration.

Assumption made in Analysis of USM

(i) the rate of work material removal is proportional to the volume of work material per impact.

(ii) the rate of work material removal is proportional to the

(iv) all impacts are identical

(V) All abrasive grains are identical and spherical in shape.

So

$$\text{Volume of work material removal rate (M.R.R)} \propto \nu Z V$$

V = volume of work material dislodged/impact

Z = no. of particles making impact/cycle

ν = frequency

Note: magnetostrictive transducer used to vibrates tool at very high frequency.

Applications & Advantages:

→ It is mainly used for brittle material that have poor electrical conductivity and cannot machined by ECM/EDM.

→ It can machined semiconductors, glass, ceramics, carbides etc.

→ It can machined shapes like round, square, irregular shape hole and surface impression.

→ Ultrasonic machining is best process for making hole in glass.

→ Hole of any shape can be produced

→ tool material need not be harder than work material

Disadvantages

→ used only for hard and brittle material

→ Surface finish is poor.

→ Poor dimensional accuracy.

Tool

→ In USM, Stainless steels and Low Carbon Steel are used for making the tools.

→ The tool is made of a strong but at the same time ductile metal.

→ Tool having the same shape of the cavity to be machined.

Abrasive Slurry

→ It contains fine particle of abrasive with water as slurry.

→ The most common abrasive are (i) boron carbide (B_4C) (ii) Silicon Carbide (SiC) (iii) corundum (Al_2O_3) (iv) diamond (v) boron silicarbide (very efficient)

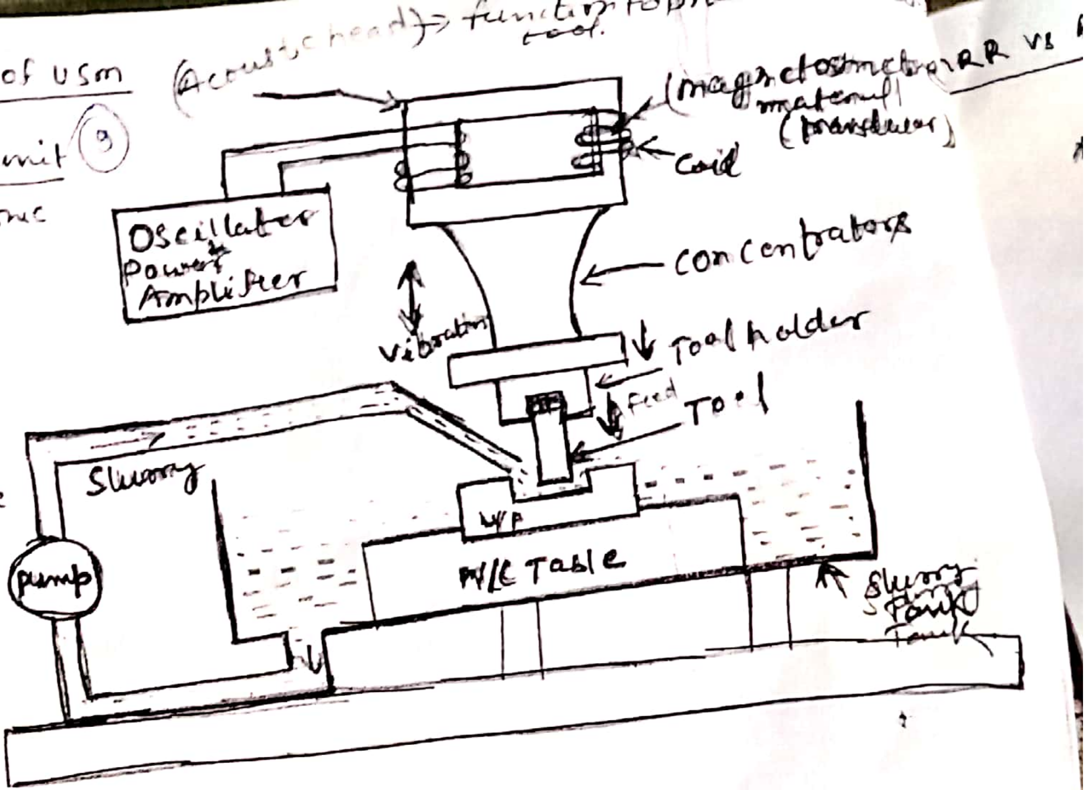
... used in the slurry, other

Working principle of USM

Ultrasonic machining unit (9)

main Element of ultrasonic machining unit are
(i) Acoustic head
(ii) feeding unit
(iii) Tool
(iv) Abrasive Slurry and pump unit
(v) body with work Table

for details description refers book Amitabh Ghosh, Page no: 335-340



Working principle:

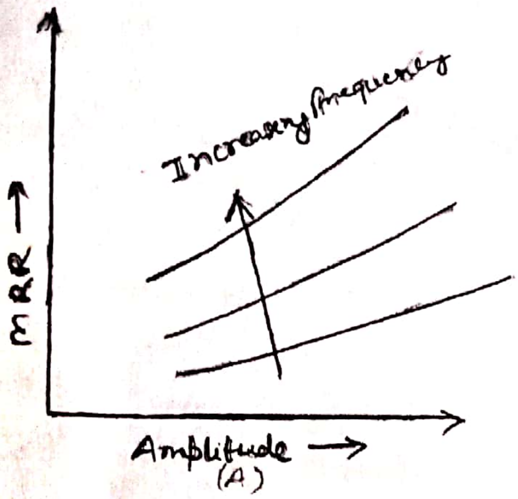
The material is removed by using abrasive slurry betn the tool and work. The tool is vibrating continuously with the help of magneto-strictive transducer. the frequency ranging from 15 to 30KHz and no contact between tool and w/p but the gap betn. tool and workpiece is filled by using abrasive slurry. when the tool is vibrating with high frequency, it induces the impact loads and acts on to the abrasive particle so that the abrasive particles will inturn trasfer the impact load on the workpiece on a small area so that work material will experience the plastic deformation and brittle fractures will takes place, which produce very small chips or wear particles which will be taken away by the abrasive slurry.

Process parameters

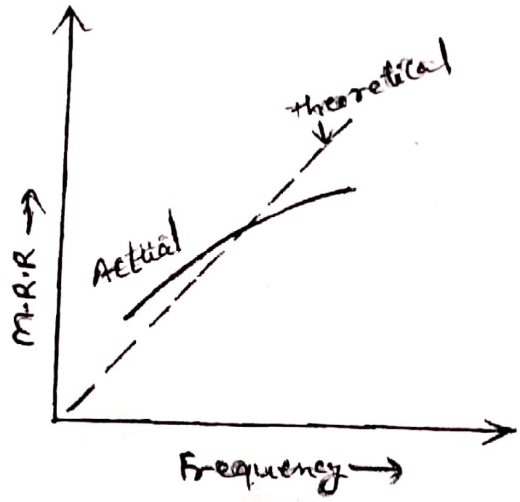
parameters which affect the process characteristics are the

(i) Frequency
(ii) Amplitude
(iii) Static loading (feed force)
(iv) hardness ratio of tool and the workpiece
(v) grain size

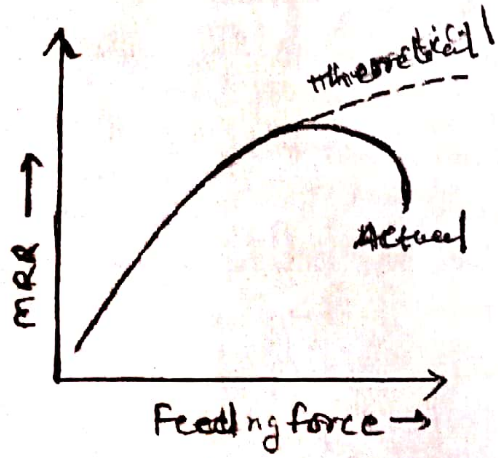
MRR vs Amplitude & frequency



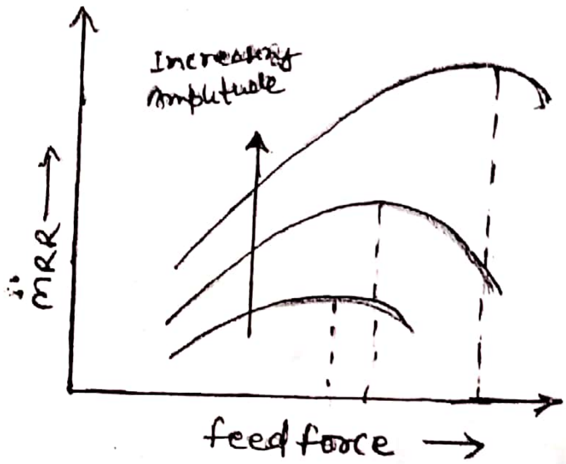
MRR vs frequency(ν)

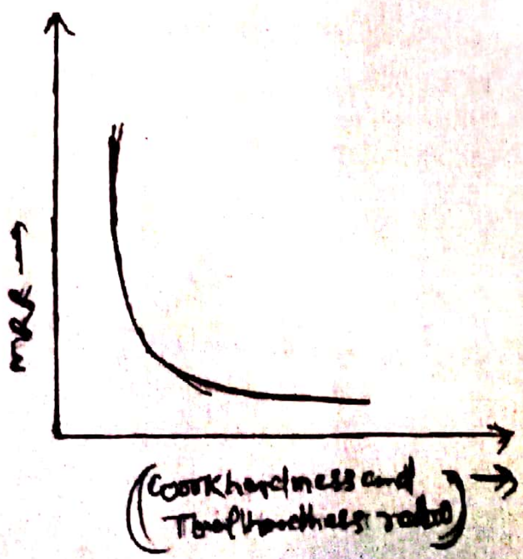


MRR vs feed force



MRR vs feed force with increasing Amplitude





Electrochemical machining (ECM)

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→ In ECM, material removed by electro-chemical action.
→ the tool of ECM is Cathod and workpiece act as an anode.
→ machining is not dependent on the mechanical or physical properties of work material. It depends upon atomic weight and valency of the work material & work should be electrical conductive.
→ Surface finish is excellent with almost stress free machine surface and without any thermal damage.
→ Commercial ECM is Carried out at a combination of low voltage high current.
→ metal is removed by maintaining an electro-lyte betn. the tool and work in a very small gap. Electrolyte is ~~independent~~ so chosen that only anode is dissolved but no deposition takes place on Cathode.

→ Electrochemical machining (ECM) is another non-conventional machining process using electrical current to remove the metal. It is based on the principle of electrolysis for material removal. michael faraday (1791-1867) discovered that if two electrodes are placed in a bath containing a conducting liquid and a d.c potential is applied across them then metal can be depleted from the anode and plated on the Cathode.

Electrolyte

Electrolyte used in ECM is basically salt solution, with water forming a large proportion. Commonly used electrolyte

(i) Chloride solution in water e.g. Sodium chloride or potassium chloride up to 0.25 kg/lit.
→ low cost & stable conductivity over a broad range of ph values but it is corrosive and produces large amount of sludge.

(ii) Sodium nitrate up to 0.50 kg/lit.
→ Less corrosive

(iii) mixture of brine and H_2SO_4

the Electrolyte should have following properties to serve the function are

→ High electrical conductivity
→ low viscosity and high sp. heat
→ chemical stability
→ Resistance to formation of passivating film on work surface.

Q What are the functions of an electrolyte in ECM? 12

Ans: The following functions of an electrolyte in ECM are

(i) Completes the electrical circuit betn the tool and the workpiece
(ii) Allow desirable machining reactions to takes place
(iii) Carry away heat generated during the operation
(iv) Carry away the waste or removed particle from the zone of machining.

ECM Tools:

→ Generally, Aluminium, copper, brass, Titanium, Cupro-nickel and Stainless Steel are used as tool materials.

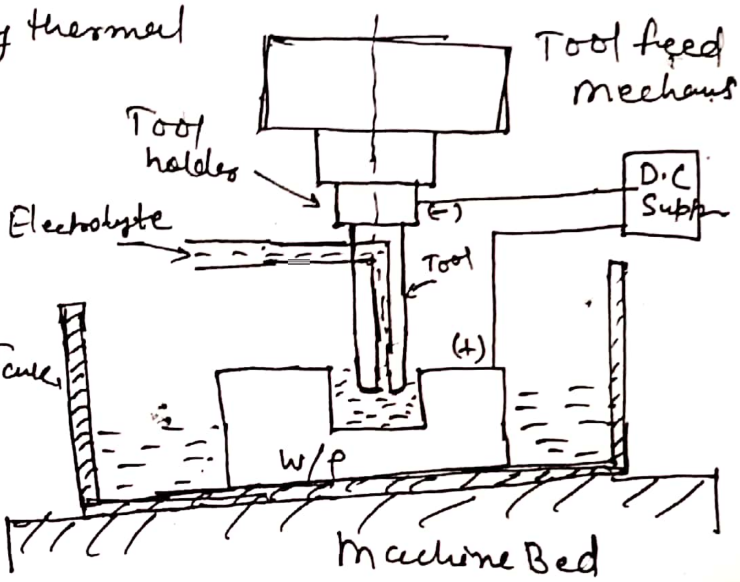
The following properties are expected of ECM tool material

(i) High electrical and thermal Conductivity
(ii) Good Stiffness
(iii) Easy machinability
(iv) High corrosion resistance

Q Why do we use DC instead of AC?

Electro-chemical machining (ECM)

→ material removed by electro-chemical Technique.
→ The tool of ECM is cathode and workpiece as an anode.
→ machining is not dependent on the mechanical or physical properties of work-material. It depends upon atomic weight and valancy of the work-material and work should be electrical conductive.
→ Commercial ECM is carried out at a combination of low voltage & high current.
→ Surface finish is excellent with almost stress free machined surface and without any thermal damage.



the working principle of ECM

ECM used the principle of electrolysis to remove metal from the workpiece. Electrolysis is based faradays law of electrolysis which is stated as "weight of substance produced during electrolysis is proportional to current passing, length of time the process used and the equivalent weight of material which is deposited. In ECM work is made anode ~~cathod~~ and the tool is made cathode. So work loses metal, but before depositing it on to the tool, it is carried away by electrolyte. for the machining with ECM, the setup is made as shown fig. When power supply is given to the tool and work. metal removed by controlled dissolution of the anode. As tool advances toward anode through the electrolyte, the metal removed from workpiece through electrical action i.e the ions are ...rated displacing from w/p and try to deposite over the tool

ions are also moving out along with electrolyte w... deposition over the tool. So mechanism of metal removal ...
ion displacement-

(14)

Advantages
(1) Complex curvature can be produced very easily
(2) No tool wear
(3) No forces are acting on the tool
(4) Excellent surface finish can be produced
(5) thermal effect of work is nill.

Disadvantage
(1) W/P material must be electrically conductive
(2) sp. cutting energy requirement are very high.
(3) Generally preferable for contours but not prefer for producing holes.
(4) machine is expensive.
(5) Sharp interior edges and corners are difficult to produce.

Application
→ used for producing turbine blades of complex shape
→ Blind complex cavities, curved surfaces
Note: Tool material is same as that of work material generally taken

(8) What are the functions of electrolyte in ECM?
Ans: (i) Completing the electrical circuit (b/w tool and workpiece) and allowing large currents to pass.
(ii) Sustaining the required electro-chemical reaction. It should be such that the work (anode) is continuously dissolved and discharge of the tool (cathode) should not occurs
(iii)

Q. What is electrolyte?

Ans. Electrolyte used in ECM is basically salt solution.

Commonly used electrolyte

(a) Chloride soln. in water (NaCl)

(b) HCl or mixture of brine and H_2SO_4.

(1S)

Calculations.

(1) $$\text{MRR in ECM} = \frac{AI}{F\rho Z} \ \text{mm}^3/\text{min}$$

where A = atomic wt. of work material.

I = Current in Amp.

F = Faraday's const. = 96500

ρ = density

Z = Valency i.e no. of valence electrons

$$MRR = \frac{IA}{FZ} \ \text{gm/sec.}$$

(2) Current density (J) = Amount of current flow per unit area = I/Area.

So Current density in the gap (J) betn tool and work $= \frac{K(V-\Delta V)}{y}$ where

$= \frac{KV}{y}$ when overvoltage is not mention.

$1/K$ = Sp. resistance of electrolyte (Ω-cm)

y = Inter electrode gap in c.m

V = voltage supply

ΔV = extra-voltage required for ion transfer.

(3) Electrode feed rate $= \frac{MRR}{\text{Surface area}}$ c.m/sec.

(4) Equivalent wt $= (A/Z)$

or Gram equivalent wt. of the metal

(5) An alloy of 18% Co, 62% Ni & 20% Cr

$$\left(\frac{Z}{A}\right)_{equ.} = \frac{Z_1 x_1}{A_1} + \frac{Z_2 x_2}{A_2} + \frac{Z_3 x_3}{A_3} \ldots$$

$Z_{Co} = 2 \mid A_{Co} = 58.93$

$$= \frac{2 \times 0.18}{58.93} + \frac{2 \times 0.62}{} + \frac{6 \times 0.2}{}$$

Electro-chemistry of ECM process

Electrolysis process is governed by two laws proposed by Faraday

(i) The amount of chemical change produced by an electric current, that is the amount of any material dissolved or deposited, is proportional to the quantity of electricity passed.

(ii) The amount of different substances dissolved or deposited by the same quantity of electricity are proportional to their chemical equivalent weights.

In quantitative form,

$$m \propto ItE$$

$$\boxed{m = \frac{ItE}{F}}$$

$$E = \frac{\text{Atomic wt. (A)}}{\text{No. of valency electrons (Z)}}$$

where
m = weight (in grams) of material dissolved or deposited
I = current in Amp
t = time
E = gram equivalent weight of the material
F = Const. of proportionality = Faraday's const. = 96,500 coulombs.

Material removal rate (MRR)

$$\boxed{\text{MRR in ECM} = \frac{IA}{FZ} \text{ gm/sec}}$$

$$\boxed{\text{MRR} = \frac{IA}{\rho F Z} \text{ mm}^3/\text{sec.}}$$

$$\left(\because \frac{m}{t} = \frac{IE}{F} \text{ gm/s} \qquad \frac{\rho V}{t} = \frac{IE}{F} \Rightarrow \frac{V}{t} = \frac{IE}{\rho F} \text{ mm}^3/\text{sec} \right)$$

A = Atomic wt. of work material
ρ = density of workpiece
Z = valency i.e. no. of valency electrons.

(Q) In ECM process with a pure iron w/p, a removal rate of 5 cm^3/min is desired. Determine the current required.

Soln
Gram atomic weight (Fe) = 56 g
Valence at which dissolution takes place (Z) = 2
density of iron (ρ) = 7.8 g/cm^3

$$\Rightarrow \frac{5}{60} \text{ cm}^3/\text{sec} = \frac{IA}{\rho F Z}$$

$$\Rightarrow \frac{5}{60} = \frac{I \times 56}{7.8 \times 96500 \times 2}$$

To machined an alloy by ECM

$$MRR = \frac{I}{\rho F \left(\frac{Z}{A}\right)_{equ.}} \quad cm^3/sec.$$

$$= \frac{I}{F (Z/A)_{equ}} \quad gm/sec$$

An alloy of x_1% of A_1, x_2% A_2, x_3% of A_3 - - -

$$\left(\frac{Z}{A}\right)_{equ.} = \frac{Z_1 x_1}{A_1} + \frac{Z_2 x_2}{A_2} + \frac{Z_3 \cdot x_3}{A_3} + \cdots$$

Exp An alloy of 18% Co, 62% Ni & 20% Cr.

$A_1 = A_{Co} = 58.93$, $z_1 = 2$

$A_2 = A_{Ni} = 58.71$, $z_2 = 2$

$A_3 = A_{Cr} = 51.99$, $z_3 = 6$

term $\left(Z/A\right)_{equ.} = \frac{Z_1 x_1}{A_1} + \frac{Z_2 \cdot x_2}{A_2} + \frac{Z_3 \cdot x_3}{A_3}$

Alloy $= \frac{2 \times 0.18}{58.93} + \frac{2 \times 0.62}{58.71} + \frac{6 \times 0.20}{51.99}$

$(Z/A)_{eq} = 0.0503$

(Q) machined above alloy by ECM, ρ_{Alloy} = density of alloy $= 8.28 g/cc$

$I = 500$ Amp

$F = 96500$ Coulombs/mole

find MRR

$$MRR = \frac{I}{\rho F (Z/A)_{eq}} = \frac{500}{8.28 \times 96500 \times 0.0503}$$

$$= 0.0124 \ cc/sec.$$

Chemical Machining (CHM)

→ It is an ancient process being used for engraving the metals for ornaments, for making decorative articles and for printing applications.

→ These days, it is used for a variety of other applications as well, such as production of printed circuit boards, engraving, machining aircraft parts etc.

→ The process involves use of acids or alkalis (Etchant) to remove unwanted material. Portions not to be machined are coated with a material resistant to the reactive solution.

→ Very intricate geometries can be generated from this machining process.

→ CHM removes material in a controlled manner by the application of maskant and Etchant

Maskant:

→ "It does not allow etchant to reach and react with workpiece to dissolve it."

→ It include material like vinyl, neoprene etc.

→ Applied by (i) spray coating, (ii) dipping (iii) flow coating

Etchant:

→ Dissolves workpiece material by chemical action.

Material	Etchant	Etching rate (mm/min)
Al	$NaOH$, $FeCl_3$	0.03 and 0.02
Cu	$FeCl_3$, $CuCl_3$	0.05 & 0.03
Cr	HCl	0.013
Gold	$HCl : HNO_3 = 3 : 1$	0.035
Magnesium	HNO_3	0.035
Molybdenum	H_2SO_4	0.025
Nickle	$FeCl_3$	0.025

After drying, coating on the portion required to be machined is peeled off. The component is then dipped in etchant bath ~~for machining~~ for a certain amount of time for getting a certain depth of cut so proper machining can be carried out.

→ Chemical machining cannot produce highly accurate parts tolerences of upto ± 0.13 may be obtained.