Electrical Energy Based Removing Techniques

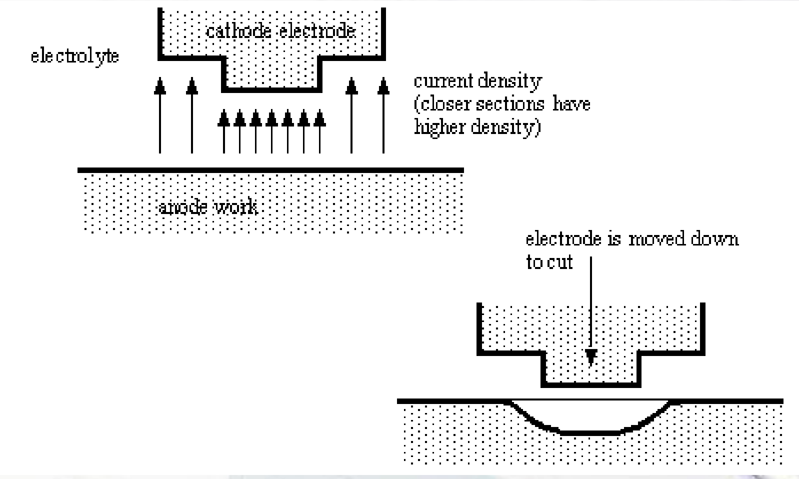
- Electrochemical grinding (ECG)
- Electrochemical machining (ECM)

ECG and ECM

- In electrochemical material removal an electrical field in an electrolyte destroys the atomic bonds of the material.
- Under electrochemical removal techniques we will review electrochemical grinding (ECG) and electrochemical machining (ECM). The latter includes micro-electrochemical machining (μ-ECM), electrochemical jet etching, laser-assisted electrochemical jet micromachining and scanning electrochemical microscope machining (SECMM).

ECG and ECM

- The physics - an electrode and work piece (conductor) are placed in an electrolyte, and a potential/ voltage is applied. On the anode (+) side the metal molecules ionize (lose electrons) break free of the work piece, and travel through the electrolyte to the other electrode (a cathode; has a - charge; a surplus of electrons).
- Faraday's law states that:



$$m = \frac{It\varepsilon}{F}$$

m = weight (g) of a material

I = current (A)

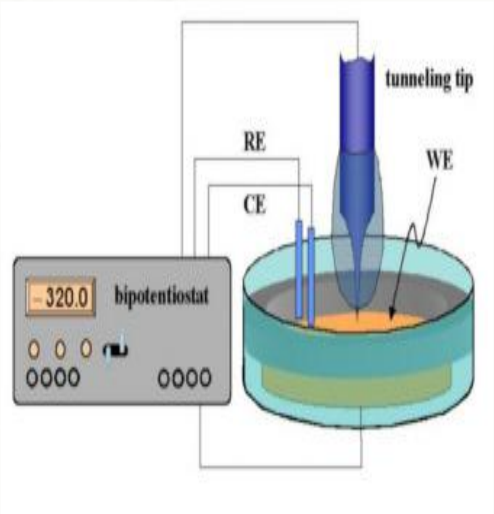
t = time (sec)

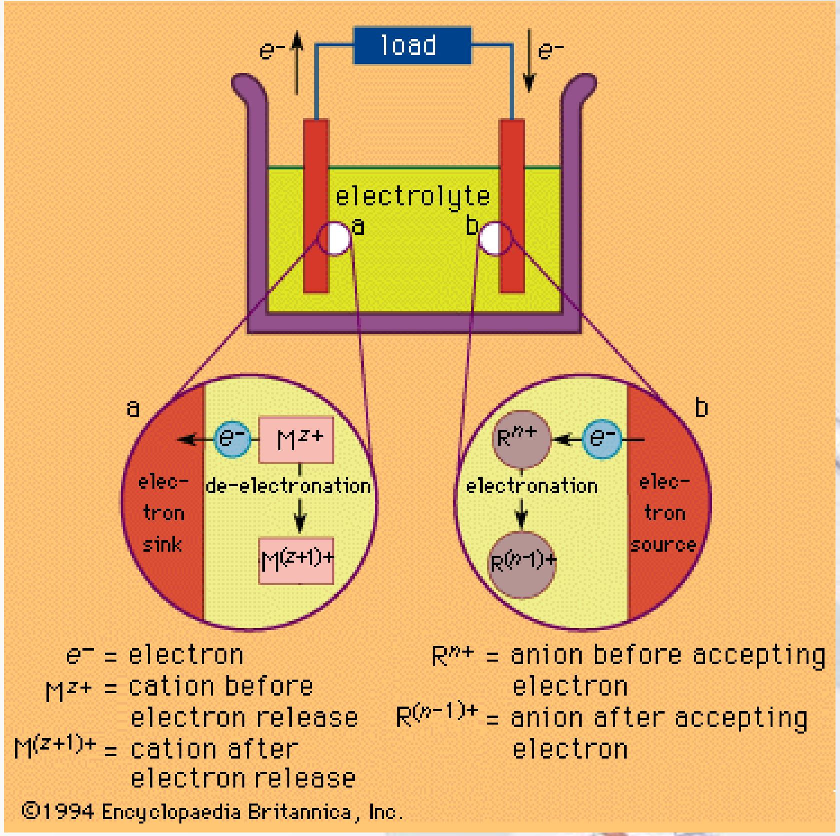
ε = gram equivalent weight of the material

F = constant of proportionality - Faraday (96,500 coulombs)

ECG and ECM

- Nomenclature of an electrochemical cell
- Scanning electrochemical microscope (SECM).



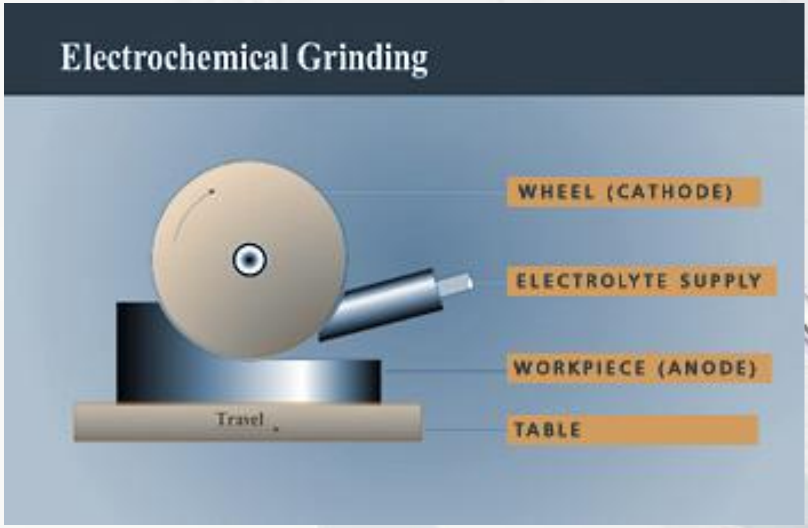


ECG

- Grinding usually constitutes a mechanical machining process that removes small amounts of material from a metallic work piece in the form of tiny chips through the contact of small, hard, sharp, nonmetallic particles often embedded in a grinding wheel.
- In electrochemical grinding (ECG), the abrasive action of an electrically conductive wheel, the cathode, accounts only for 10% of the metal removal, the remainder is electrochemical.

ECG

- Electrochemical grinding (ECG) is an electrolytic material-removal process involving a negatively charged abrasive grinding wheel, a conductive fluid (electrolyte), and a positively charged work piece.
- Work piece material corrodes into the electrolyte solution. ECG is similar to electrochemical machining except that the cathode is a specially constructed grinding wheel instead of a tool shaped like the contour to be machined.



ECG Parameters

- Power requirements: In ECG operations, d-c power is used, usually at a potential of 4-14 V; current ranges from 50-3000 A.
- Current density: Generally, current densities range from 77 A/cm^2 when tungsten carbide is ground to 230 A/cm^2 when steels are ground.
- Metal removal rates: Faraday's laws closely apply to ECG in that metal removal rate is almost directly proportional to current density.
- A rule of thumb for estimating metal removal rate for most materials is 0.16 cm^3/min for each 100 A of applied current. Usually, on materials harder than Rc 45, metal removal rates for ECG are up to 10 times faster than rates possible with conventional grinding.
- Wheel speed: In ECG operations, wheel speed is most often between 25-35 m/s. Wheel speed is important in that the wheel serves as an electrolyte pump and helps maintain an even flow of fluid between the wheel and work.
- Tolerances: With careful control of electrolyte temperature, specific gravity, and conductivity, it is possible to produce parts to within 0.005 mm.

ECG Advantages

- In operations in which ECG can be applied, it produces results far beyond those that conventional grinding methods can provide. In my cases it can reduce abrasive costs up to 90%.
- Also, because it is a cool process, ECG can be used to grind any electrically conductive material without damage to it from heat. In addition, this process can grind steel or alloy steel parts without generating any burr. Thus, the costly operation of subsequent deburring is automatically eliminated.
- ECG has found many applications in the aerospace, automotive instrumentation, textile, and medical manufacturing industries, among others. The process is most frequently used to grind hard, tough materials, because ECG is performed with significantly less wheel wear than conventional grinding. Surgical needles and thin-wall tubing are cut effectively due to the low forces generated in the ECG process.

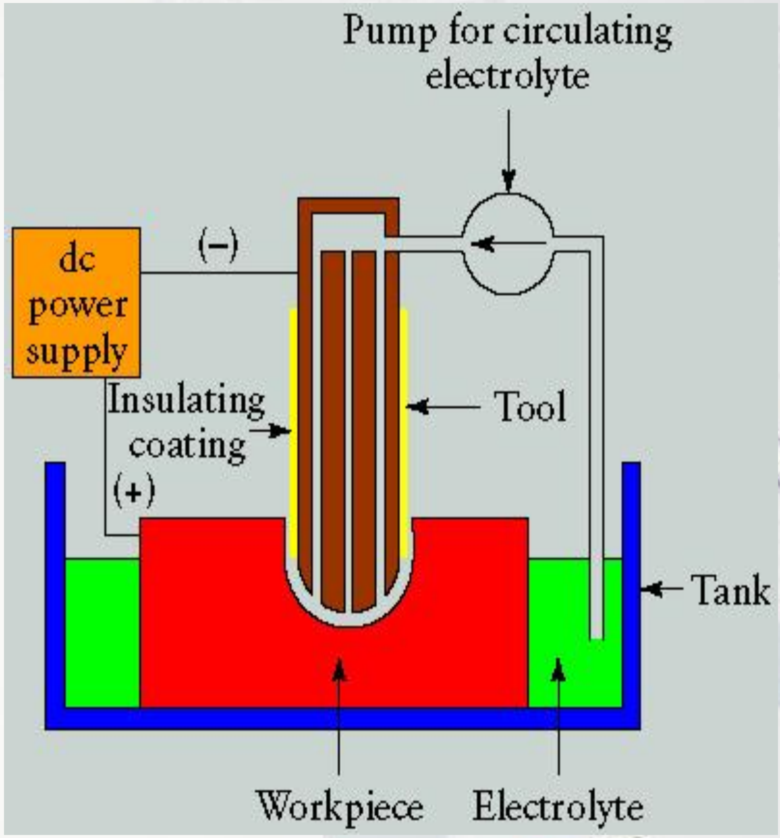
Conductive grinding wheels

ECG Advantages

- Improved wheel life
- Burr free
- No work hardening
- Stress free
- Better finish
- No cracking
- Less frequent wheel dressing
- No metallurgical damage from heat
- Faster for tough materials
- No wheel loading or glazing
- More precise tolerances

ECM

- Electrochemical machining (ECM) is an electrolytic material removal process involving a negatively charged shaped electrode (cathode), a conductive fluid (electrolyte), and a conductive workpiece (anode).
- ECM is characterized as "reverse electroplating." The tool must be properly shaped, and provision for waste removal must be made.



ECM

- Electrochemical machining (ECM) has been developed initially to machine these hard to machine alloys, although any metal can so be machined.
- ECM is an electrolytic process and its basis is the phenomenon of electrolysis, whose laws were established by Faraday in 1833.
- The first significant developments occurred in the 1950s, when ECM was investigated as a method for shaping high strength alloys.
- As of the 1990s, ECM is employed in many ways, for example, by automotive, offshore petroleum, and medical engineering industries, as well as by aerospace firms, which are its principal user.

ECM

- The tool is typically made of copper, brass, or stainless steel, while the most commonly used electrolyte is a concentrated solution of inorganic salts, such as sodium chloride, and the direct current power source is low voltage and high amperage.
- In the ECM process, the dc power source charges the workpiece positively and charges the tool negatively. As the machine slowly brings the tool and workpiece close together, perhaps to within 0.010 of an inch, the power and electrolyte flow are turned on. Electrons flow across the narrow gap from negative to positive, dissolving the workpiece into the shape as the tool advances into it. The recirculating electrolytic fluid carries away the dissolved material as a metal hydroxide.

ECM

- Electrochemical machining (ECM) historically followed ECG.
- In ECM one employs a cathode electrode shaped to provide the complementary structure in an anode work piece.
- A highly conductive electrolyte stream separates the cutting tool from the work piece, and metal removal is accomplished by passing a dc current of up to 100A/cm^2 through the salt solution cell. As the cathode tool approaches the anode work piece it erodes its complementary shape in it. Thus complex shapes may be made from a material such as soft copper and used to produce negative duplicates of it. The process is also called electrochemical sinking.
- The pressurized electrolyte (concentrated solutions of inorganic salts such as sodium chloride, potassium chloride, and sodium nitrate) passes at high speed (10 to 60 m/s) through the gap (about 0.1 to 0.6 mm) between the work piece and the tool to prevent metal ions from plating onto the cathode tool and to remove the heat that is generated as a result of the high current flow.

ECM

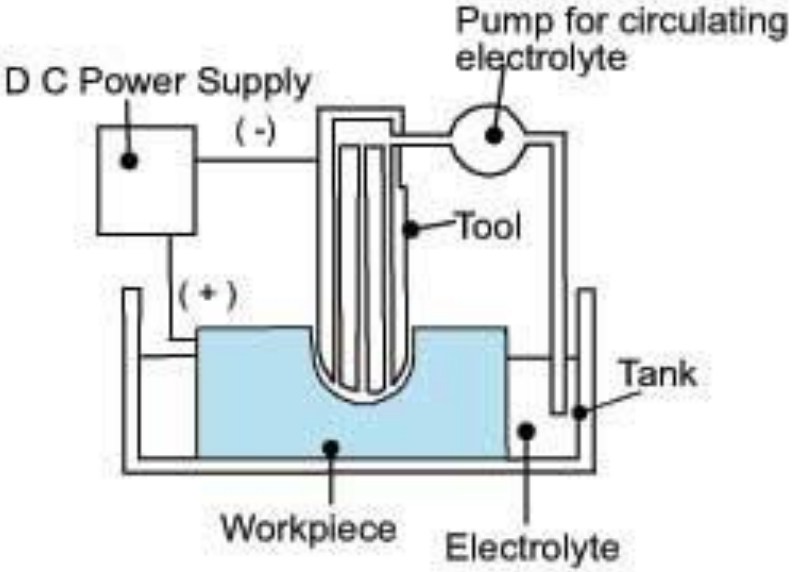
- The cathode is advanced into the anode work piece at a rate matching the dissolution rate, which is between 0.5 and 10 mm/min when applying current densities of 10 to 100 A/cm^2. The supply voltage commonly used in ECM ranges from 5 to 20 V, the lower values being used for finish machining (creating of a final smooth surface) and the higher voltages for rough machining. The rate of material removal is the same for hard or soft materials, and surface finishes are between 0.3 and 1 µm. These cutting speeds and surface finishes are comparable to those of EDM.
- The cathode tool must have these four characteristics: be machinable, rigid (high Young's modulus), be a good conductor and have good corrosion resistance. The three most common cathode materials used are copper, brass, and stainless steel.
- Because there is no actual contact between the tool and the work, the tool does not have to be harder than the work, as in traditional machining methods. Hence, this is one of the few ways to machine very hard material; another is spark-discharge machining.

ECM: Advantages

- Components are not subject to either thermal or mechanical stress.
- There is no tool wear in ECM.
- Non-rigid and open work pieces can be machined easily as there is no contact between the tool and workpiece.
- Complex geometrical shapes can be machined repeatedly and accurately
- ECM is a time saving process when compared with conventional machining
- During drilling, deep holes can be made or several holes at once.
- ECM deburring can debur difficult to access areas of parts.
- Fragile parts which cannot take more loads and also brittle material which tend to develop cracks during machining can be machined easily in ECM
- Surface finishes of 25 μ in. can be achieved in ECM

ECM

- We close off this section with a Table comparing EDM with ECM, using conventional mechanical machining
- In this Table we list metal removal rates (MRR), tolerance, surface finish and damage depth, and required power.



Electro-chemical Machining

ECM

TABLE Machining Characteristics of EDM and ECM

PROCESS	MRR mm^3/min	TOLERANCE micron	SURFACE FINISH micron	DAMAGE DEPTH micron	POWER watts
ECM	15,000	50	0.1-2.5	5	100,000
EDM	800	15	0.2-1.2	125	2700
CNC	50,000	50	0.5-5	25	3000

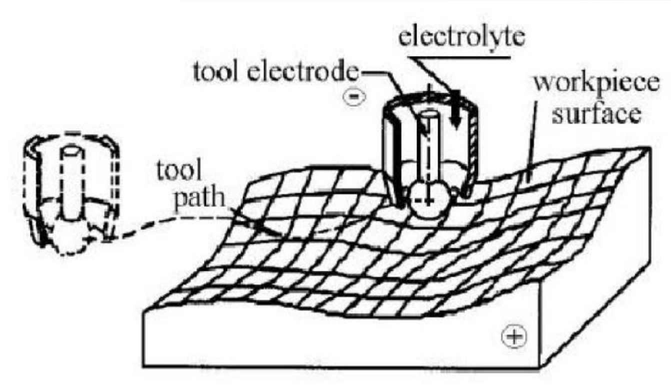
Note: MRR = metal removal rate; tolerance = tolerance maintained; surface finish = surface finish required; damage depth = depth of surface damage; ECM = electrochemical machining; EDM = electro-discharge machining; CNC = computer numerical control machining.

ECM

- The metal removal rate by ECM is much higher than that of the EDM machining with a metal removal rate 0.3 that of CNC, whereas EDM is only a small fraction of the CNC material removal rate.
- Power requirements for ECM are comparatively high.
- The tolerance obtained by EDM and ECM is within the range of CNC machining, which means satisfactory dimensional accuracy can be maintained. All processes obtain satisfactory surface finishes. Depth of surface damage is very small for ECM, whereas it is very high in the case of EDM. For this reason, ECM can be employed for making dies and punches.
- Capital cost for ECM is very high when compared to conventional CNC machining and EDM has also a higher tooling cost than the other machining processes.

µ-ECM

- The application of ECM in thin film processing and in the fabrication of microstructures is referred to as electrochemical micromachining (EMM) or micro electrochemical machining µ-ECM.
- Different from ECM, the cathode does not necessarily have the shape of the contour desired in the anode work piece. Three-dimensional shaping in EMM may involve maskless or through-mask material removal.
- The tool may also be connected to a CNC machine to produce even more complex shapes with a single tool as illustrated below.

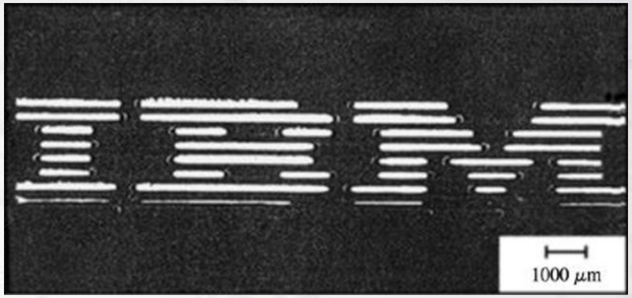


µ-ECM

- In conventional ECM the gap between cathode tool and anode work piece is typically about 150 microns, in micro ECM the gap is closer to 15-20 microns and feature sizes change from 150-200 microns to 15-20 microns as we move from the ECM to the µ-ECM domain.
- The major challenge in moving from the conventional ECM to the micro ECM domain is to control the size of the reaction region. Methods to accomplish this include:
  - A. Reduce the size of electrodes –Micro EDM is used
  - B. Shield the electrode –for stray currents
  - C. Gap control strategies
  - D. Use ultra short-pulsed voltages having time duration in the ranges of nanoseconds
- With electrochemical micromachining (EMM), most metals, alloys, and conducting ceramics of interest in the microelectronics and MEMS/NEMS industry can be anodically dissolved in a variety of neutral salt electrolytes such as sodium nitrate, sulfate, or chloride.

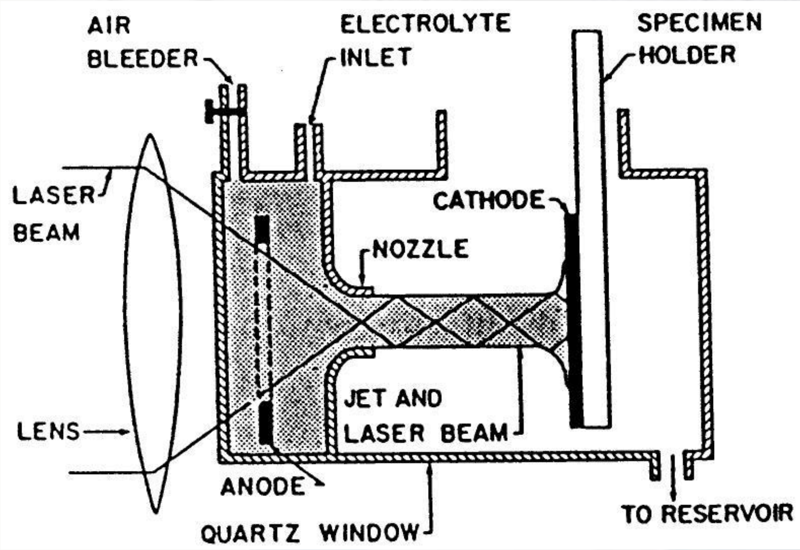
Electrochemical Jet–Etching and Laser-Assisted Electrochemical Jet-Etching

- Thin film patterning by maskless EMM may be accomplished by highly localized material removal induced by the impingement of a fine electrolytic jet emanating from a small nozzle.
- An interesting variation on electrochemical jet etching is a combination of a fluid impinging jet and laser illumination
- In laser-enhanced electrochemical jet etching, properly chosen lasers, whose energy is not absorbed by the etching solution but is absorbed by the solid, cause local heating of the substrate (up to 150 ° C) resulting in highly increased etching.



Electrochemical Jet–Etching and Laser-Assisted Electrochemical Jet-Etching

- The jet is used as a light pipe for the laser and at the same time as a means for the local high rate of supply of ions. For stainless steel, etch rates of 10 μm/sec have been demonstrated using laser-enhanced electrochemical jet machining.
- Water jet etching is a mechanical process. Water jet guided laser etching without the electrochemical component is a purely thermal technique. In this important method, a fine waterjet again guides the laser beam, provides cooling for the work-piece and expels the molten material.



Scanning Electrochemical Microscope (SECM)

- The scanning electrochemical microscope (SECM) is a scanned probe microscope (SPM) related to the familiar scanning tunneling (STM) and atomic force microscopes (AFM).
- All SPMs operate by scanning or "rastering" a small probe tip over the surface to be imaged. In SECM, imaging occurs in an electrolyte solution with an electrochemically active tip. In most cases, the SECM tip is an ultramicroelectrode (UME) and the tip signal is a Faradaic current from an electrochemical reaction at the surface.
- A scanning electrochemical microscope (SECM) can also be used for local etching and deposition with high resolution in the x, y and z dimensions, basically forming a high-resolution electrochemical machining setup.