Machining – ABRASIVES

Chapter 9

Roughness (R_a)

Process	mm	50	25	12.5	6.3	3.2	1.6	0.8	0.40	0.20	0.10	0.05	0.025	0.012
	min.	2000	1000	500	250	125	63	32	16	8	4	2	1	0.5
Flame cutting			■	■										
Snagging (coarse grinding)			■	■	■									
Sawing			■	■	■	■	■							
Planing, shaping				■	■	■	■							
Drilling					■	■	■							
Chemical machining					■	■	■							
Electrical-discharge machining						■	■							
Milling					■	■	■	■						
Broaching						■	■	■						
Reaming						■	■	■						
Electron-beam machining					■	■	■	■						
Laser machining					■	■	■	■						
Electrochemical machining						■	■	■	■	■				
Turning, boring					■	■	■	■						
Barrel finishing								■	■	■				
Electrochemical grinding									■	■				
Roller burnishing										■				
Grinding							■	■	■	■	■			
Honing							■	■	■	■	■			
Electropolishing							■	■	■	■	■			
Polishing									■	■	■			
Lapping									■	■	■	■		
Superfinishing										■	■	■		

■ Average application

□ Less frequent application

Grinding

- When the workpiece material is too hard or too brittle
- When the workpiece shape is difficult to produce with sufficient accuracy by conventional cutting methods

Abrasives: small, hard particles with sharp edges and irregular shape

Process mechanics: Removal of small amount of material from a surface by a cutting process that produces tiny chips

Conventional abrasives:

aluminium oxide

silicon carbide

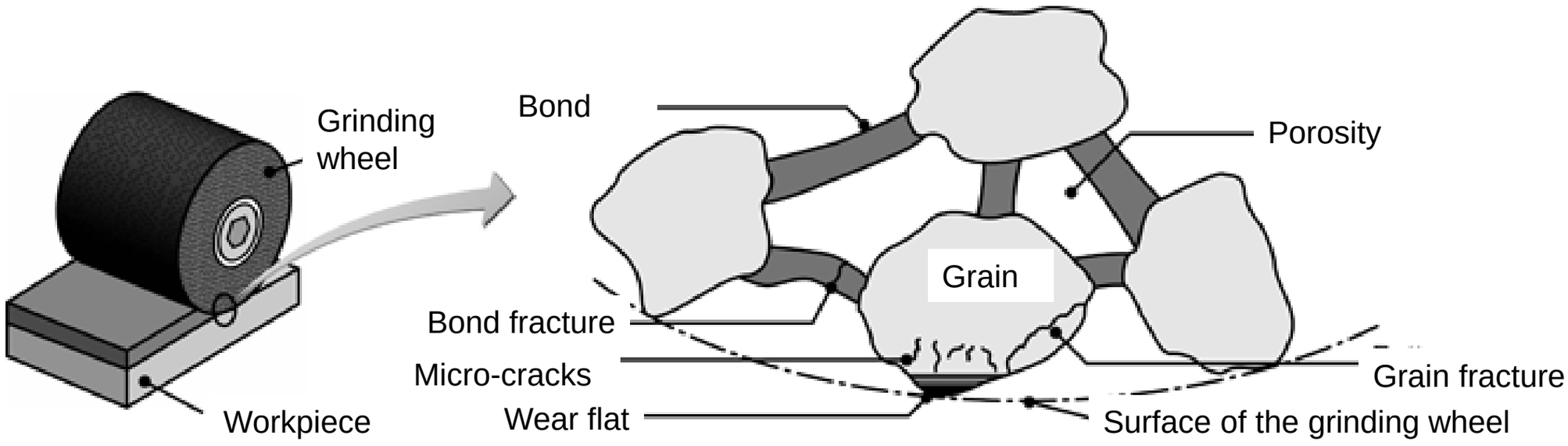
Superabrasives:

cubic boron nitride

diamond

- ✓ Hardness
- ✓ Friability
- ✓ Shape and size
- ✓ Grain size (grit number)

Grinding wheels

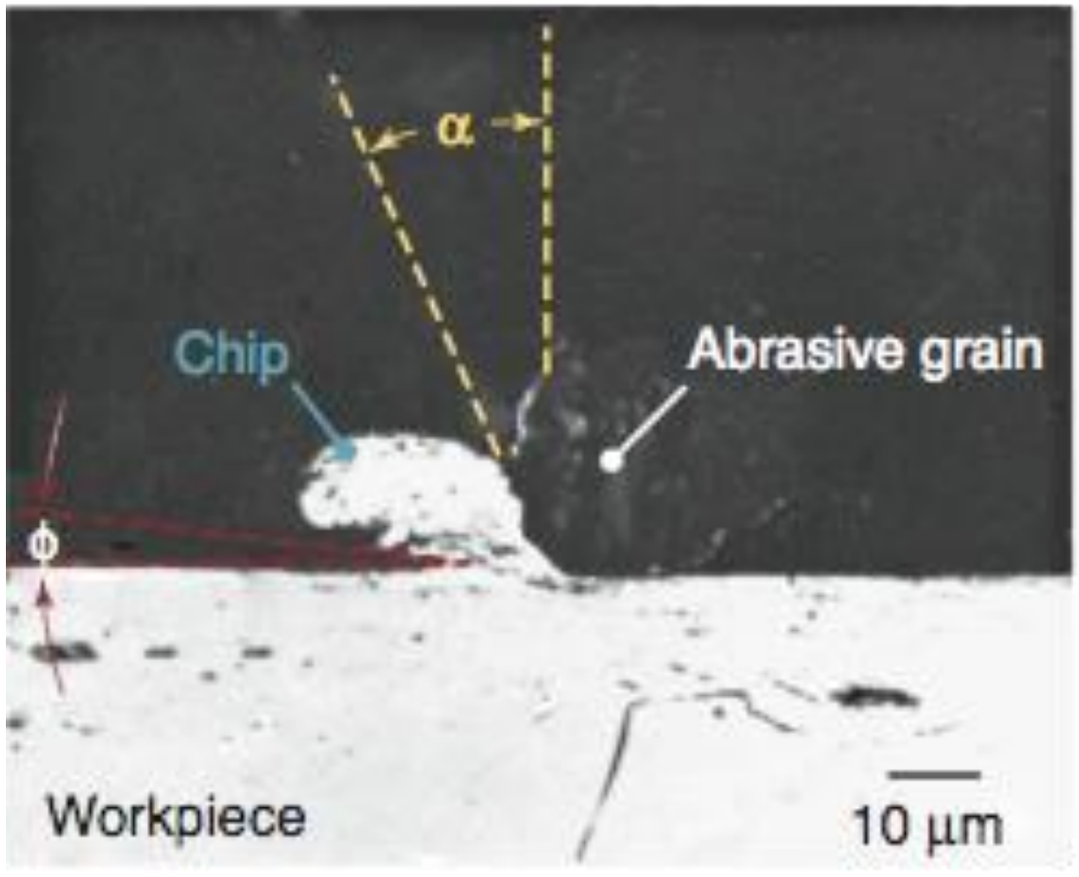


Wheel grade: measure of the bond strength and thus measure of the hardness of the bonded abrasive

Wheel structure: measure of the porosity of the bonded abrasive

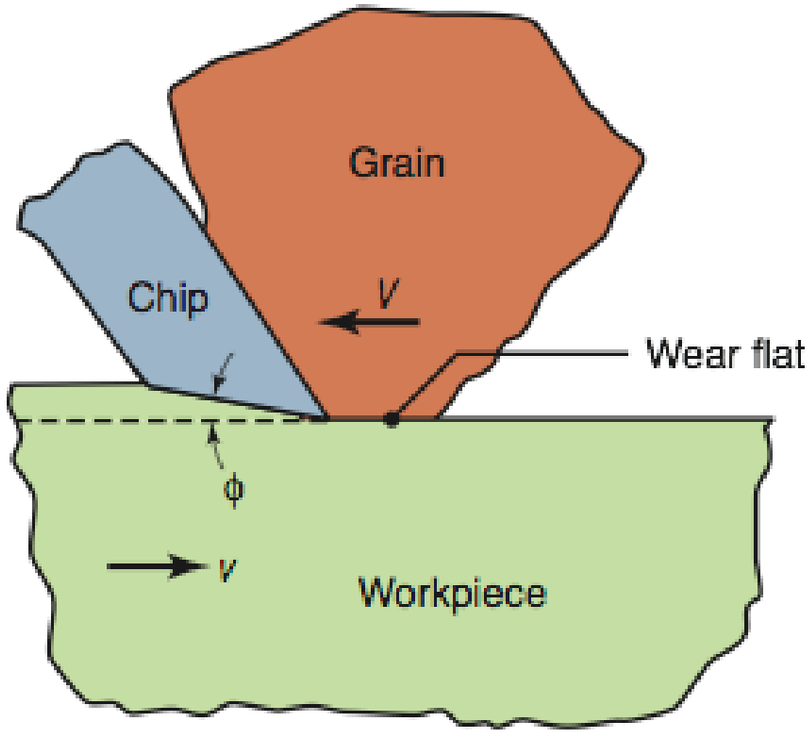
Surface grinding

- The individual grain has an irregular geometry and is spaced randomly along the periphery of the wheel
- The average rake angle of the grains is highly negative: consequently the shear angle is very low and the *shear strain* can become *very large*
- The radial positions of the grains in a grinding wheel vary
- The cutting speeds of grinding wheels are very high, typically *30 m/s*

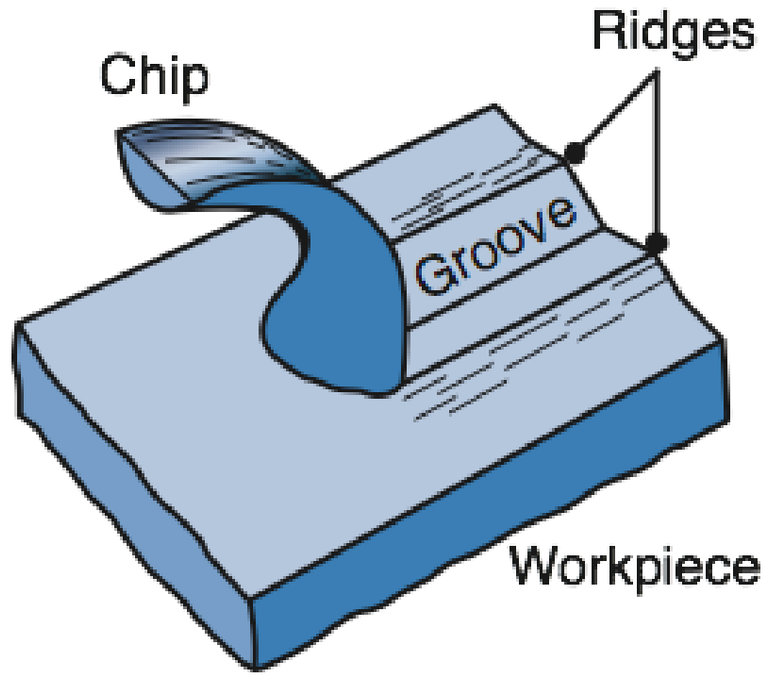


Specific energy

$$u = u_{chip} + u_{plowing} + u_{sliding}$$



Schematic illustration of chip formation by an abrasive grain. Note the negative rake angle, the small shear angle, and the wear flat on the grain.



Chip formation and plowing of the workpiece surface by an abrasive grain.

Specific energy

Workpiece Material	Hardness	Specific Energy	
		W-s/mm^3	hp-min/in^3
Aluminum	150 HB	7-27	2.5-10
Cast iron (class 40)	215 HB	12-60	4.5-22
Low-carbon steel (1020)	110 HB	14-68	5-25
Titanium alloy	300 HB	16-55	6-20
Tool steel (T15)	67 HRC	18-82	6.5-30

NB: These energy levels are *much higher* than those in cutting operations with single-point tools

- *Size effect: the smaller the size of grinding chips the greater its strength; extremely high dislocation densities in the shear zone during chip formation*
- *Wear flat: the size of the wear flat is much larger than the grinding chip, unlike in metal cutting, where flank wear is small compared with the size of the chip*
- *Chip morphology: shear strains are very large; plowing consumes energy without contributing to chip formation*

Temperature effect

The work expended in grinding is mainly converted into heat

Surface temperature rise is a function of the ratio of the total energy input to the ground surface area

Peak temperature: up to 1650˚ C

Experiments indicate that as much as half the energy is conducted to the workpiece (higher than in metal cutting)*; the heat generated by plowing and sliding is conducted mostly to the workpiece*

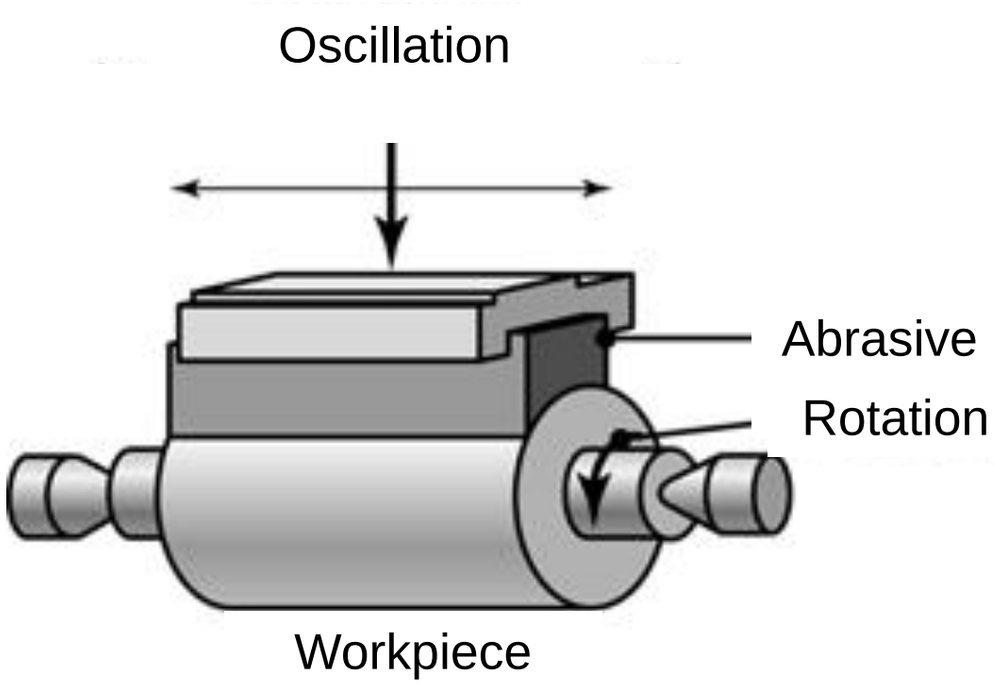
Sparks: glowing chips; exotermic reaction between hot chips and oxygen

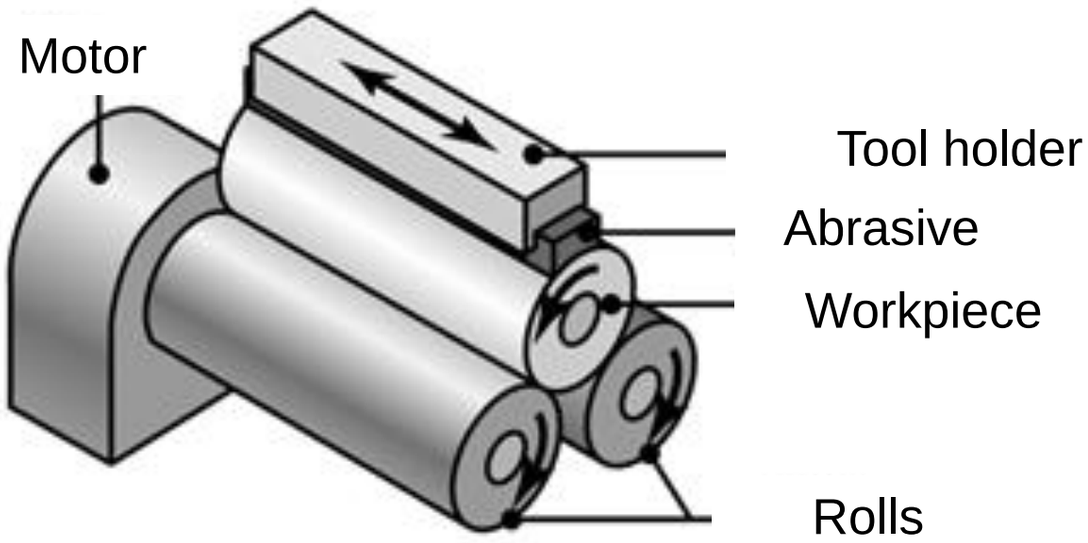
Temperature effects:

- Tempering
- Burning (metallurgical burn, heat checking)
- Residual stresses (due to temperature changes and gradients and plastic deformation of the surface)

Superfinishing/polishing

(R_a= 0.05-0.2 μm)





Hip acetabular cup before polishing

Hip acetabular cup after polishing

UNCONVENTIONAL MACHINING

Chapter 9

Nontraditional Machining

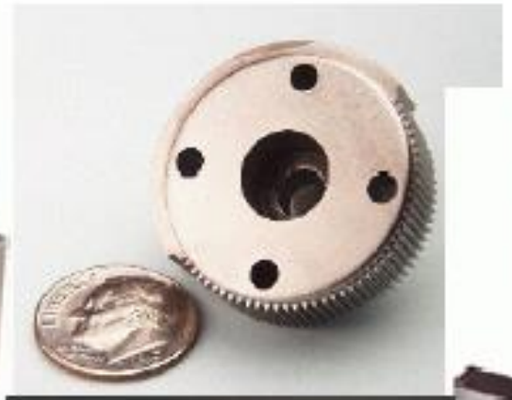
Nontraditional/ Unconventional machining:
Material removal techniques using chemical, electrical, thermal and other means

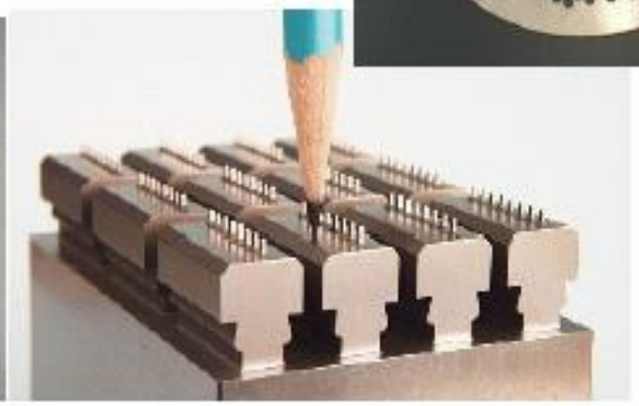
Significant economic and technical advantages, in cases where:

- Hard, strong base material
- Base material too flexible/ slender to cut or clamp
- Part geometry is complex
- Very high surface finish/ tolerances are required
- Temperature rise or residual stresses are undesirable

Nontraditional Machining Applications:

- aerospace
- microelectronics
- defense
- automotive
- semiconductor
- medical
- telecommunications
- surgical





Classification

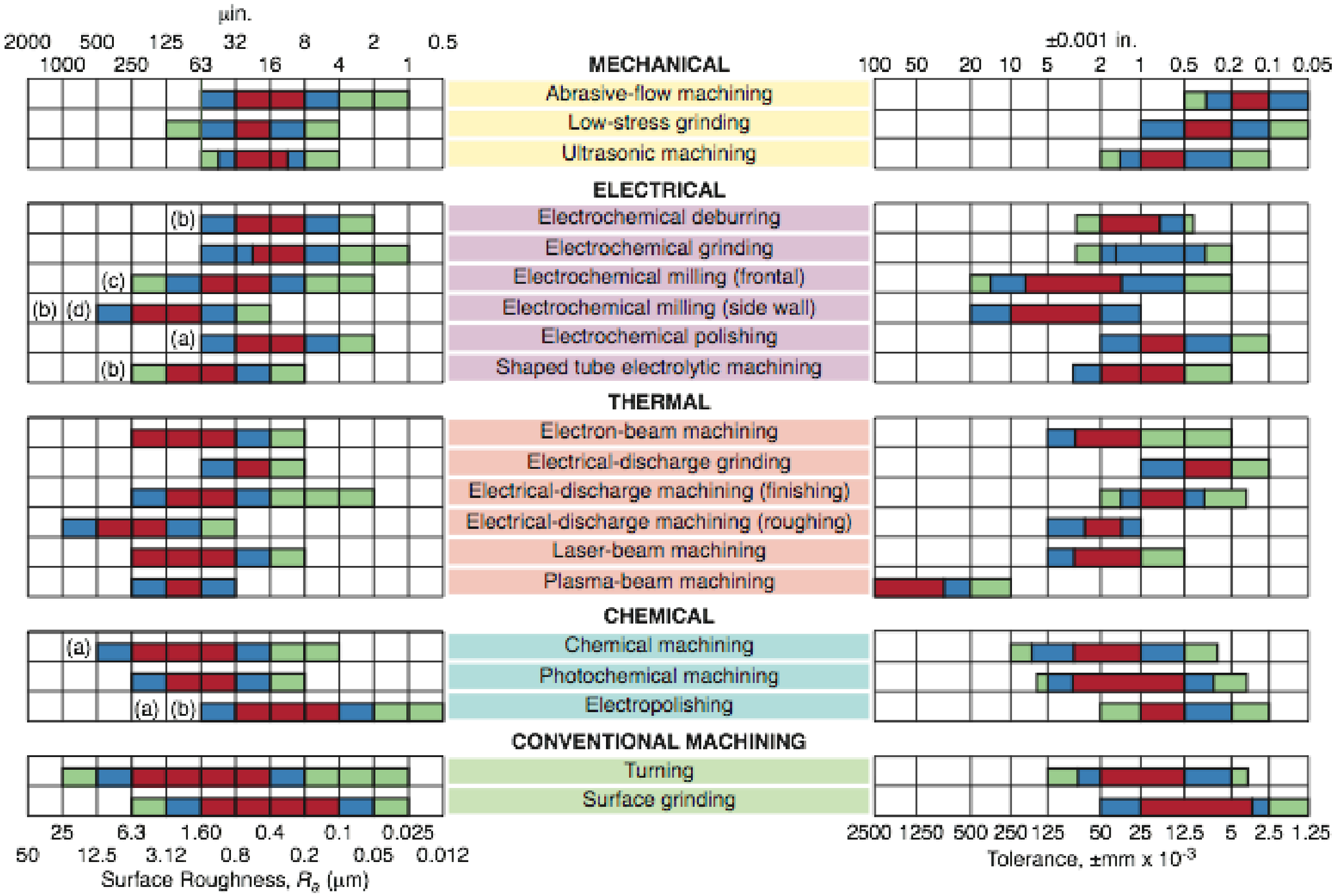
- ***Chemical*** NTM Processes
  - Chemical Machining
  - Thermochemical Machining

- ***Electrochemical*** NTM Processes
  - Electrochemical Machining
  - Electrochemical Grinding

- ***Thermal*** NTM Processes
  - Electrical Discharge Machining
  - Electron Beam Machining
  - Laser Beam Machining

- ***Mechanical*** NTM Processes
  - Waterjet Machining

Roughness and tolerances ranges

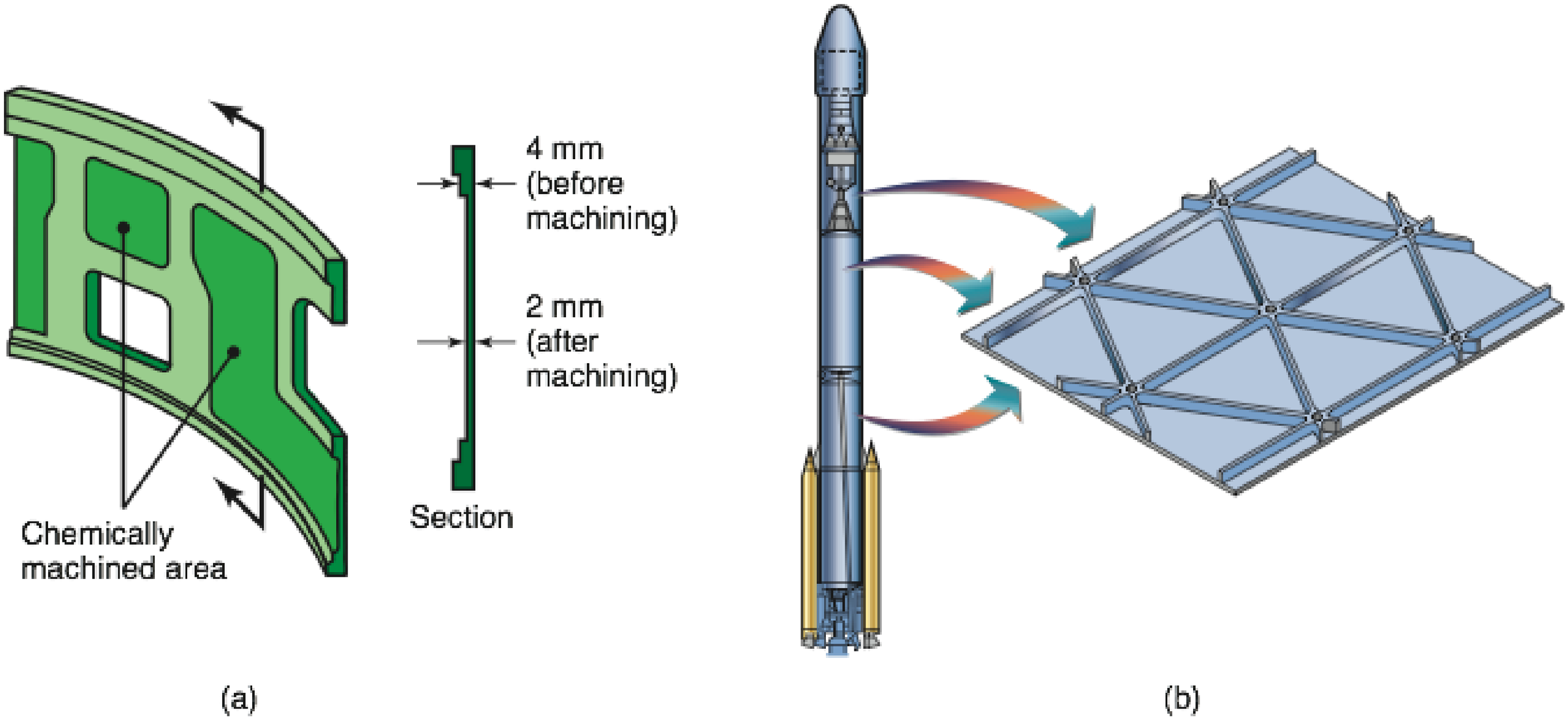


Note: (a) Depends on state of starting surface.
(b) Titanium alloys are generally rougher than nickel alloys.
(c) High current density areas.
(d) Low current density areas.

Average application (normally anticipated values)
Less frequent application (unusual or precision conditions)
Rare (special operating conditions)

Chemical machining /1

Small amounts of metal are removed from the surface through the use of chemical reagents or etchants



(a) Missile skin-panel section contoured by chemical milling to improve the stiffness-to weight ratio of the part. (b) Weight reduction of space launch vehicles by chemical milling aluminum-alloy plates. These panels are chemically milled after the plates have first been formed into shape by processes such as roll forming or stretch forming. The design of the chemically machined rib patterns can be modified readily at minimal cost.

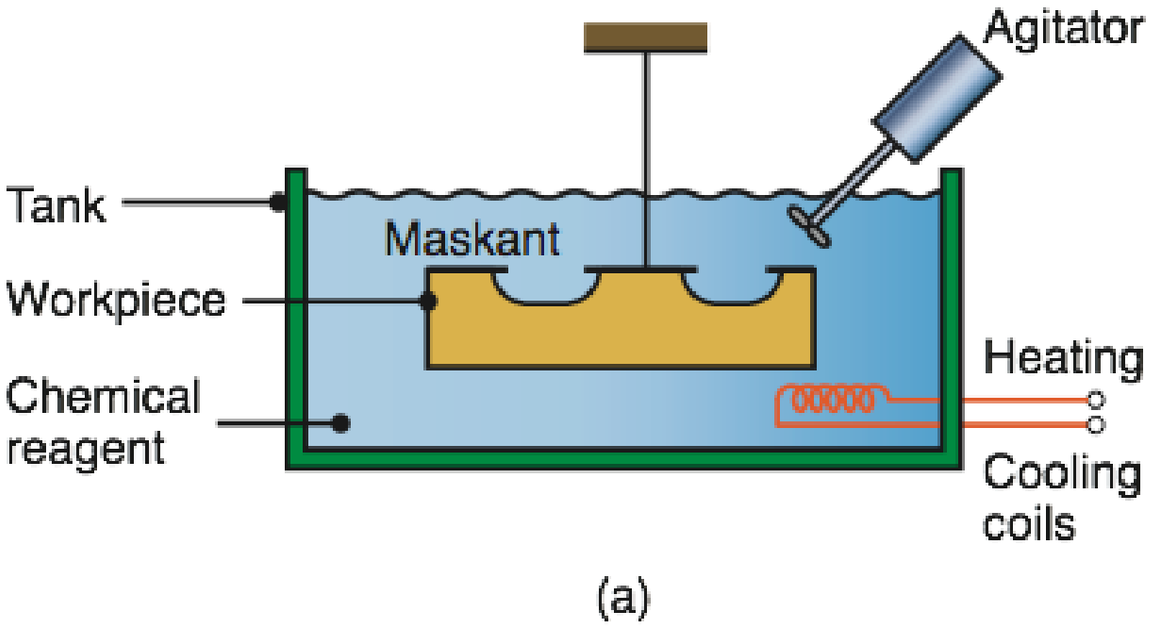
Chemical machining /2

- Shallow cavities produced on plates, sheets, forgings, and extrusions

Procedure for chemical milling steps :

1 – Residual stresses should relieved in order to prevent warping
2 – Surfaces to be thoroughly degreased and cleaned
3 - Masking material (tapes, paints, elastomers & plastics) is applied
4 – Masking is peeled off by scribe and peel technique
5 – The exposed surfaces are etched with etchants
6 – After machining the parts to be thoroughly washed to prevent further reactions with residue etchant
7 – Rest of the masking material is removed and the part is cleaned and inspected
8 – Additional finishing operations are performed on chemically milled parts
9 – This sequence is repeated to produce stepped cavities and various contours

Chemical machining /3



(a) Schematic illustration of the chemical-machining process. Note that no forces or machine tools are involved in this process. (b) Stages in producing a profiled cavity by chemical machining.

Characteristics of chemical machining

- Controlled surface corrosion of unmasked material
- Corrosion could continue through the full thickness of the workpiece

Advantages

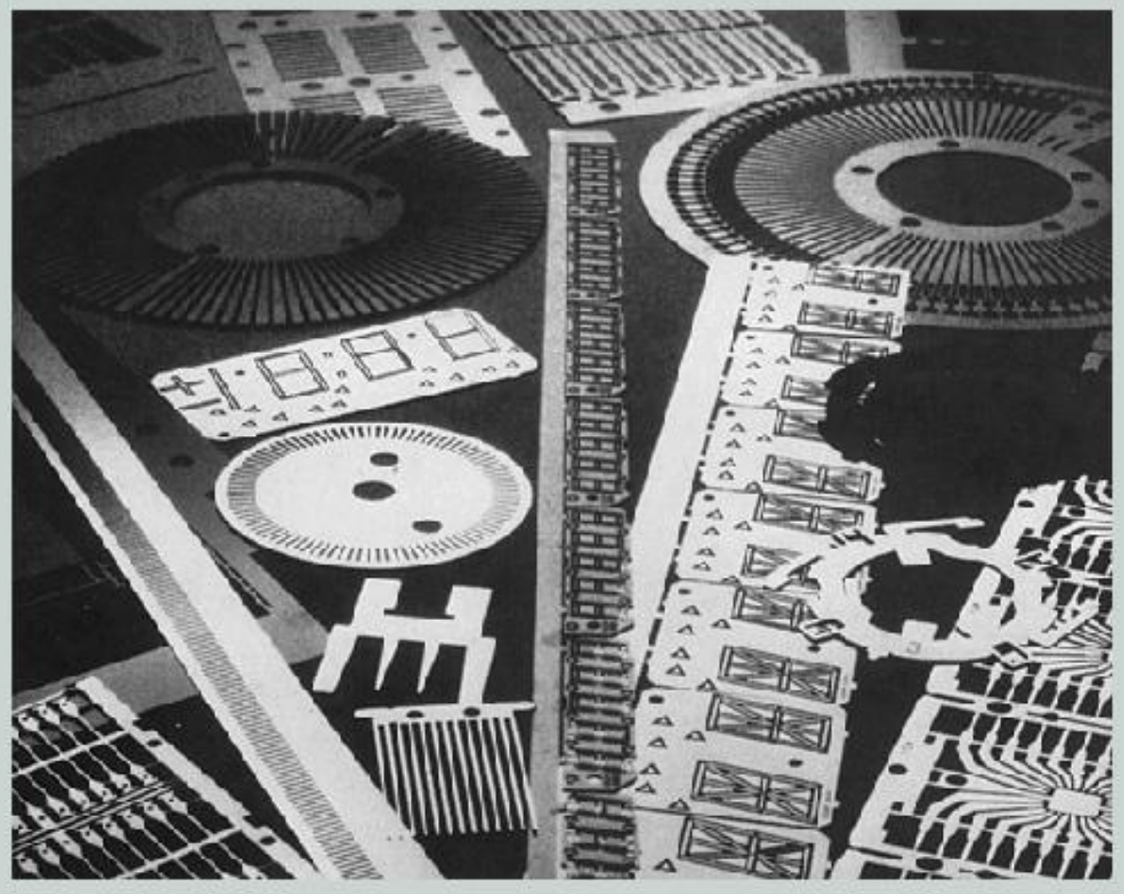
- Low capital cost once basic equipment is installed
- Many work surfaces can be “machined” simultaneously
- No cutting forces: no distortion or thermal stress problems
- Good for delicate parts
- No edge burring

Disadvantages

- Undercutting of masked areas represents a problem
- Sharp corners not possible
- Workpiece material must be homogeneous
- Disposal of chemical etchant expensive
- Operators require special protection against possible chemical spillage

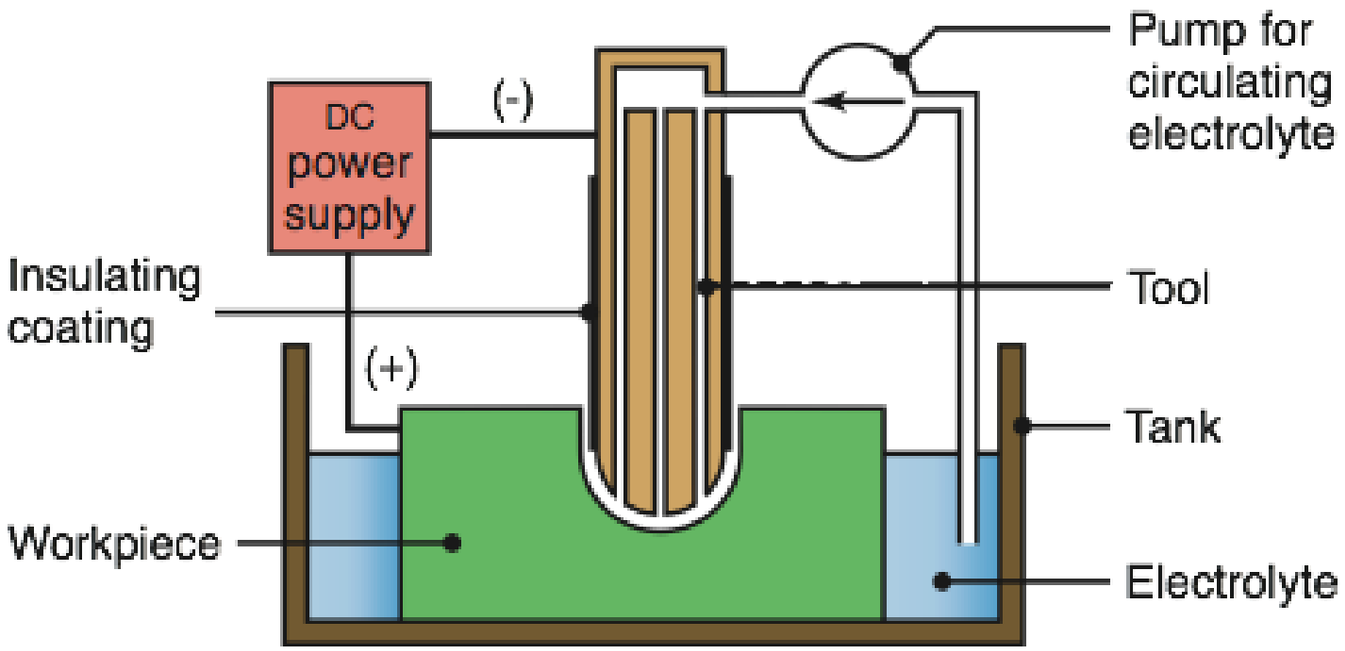
Chemical blanking

Chemical blanking is similar to chemical milling
Material is removed by chemical dissolution rather than by shearing
Burr free etching of printed-circuit boards, decorative panels, thin sheet metal stampings as well as production of small and complex shapes



Various parts made by chemical blanking. Note the fine details.

Electro-chemical machining /1



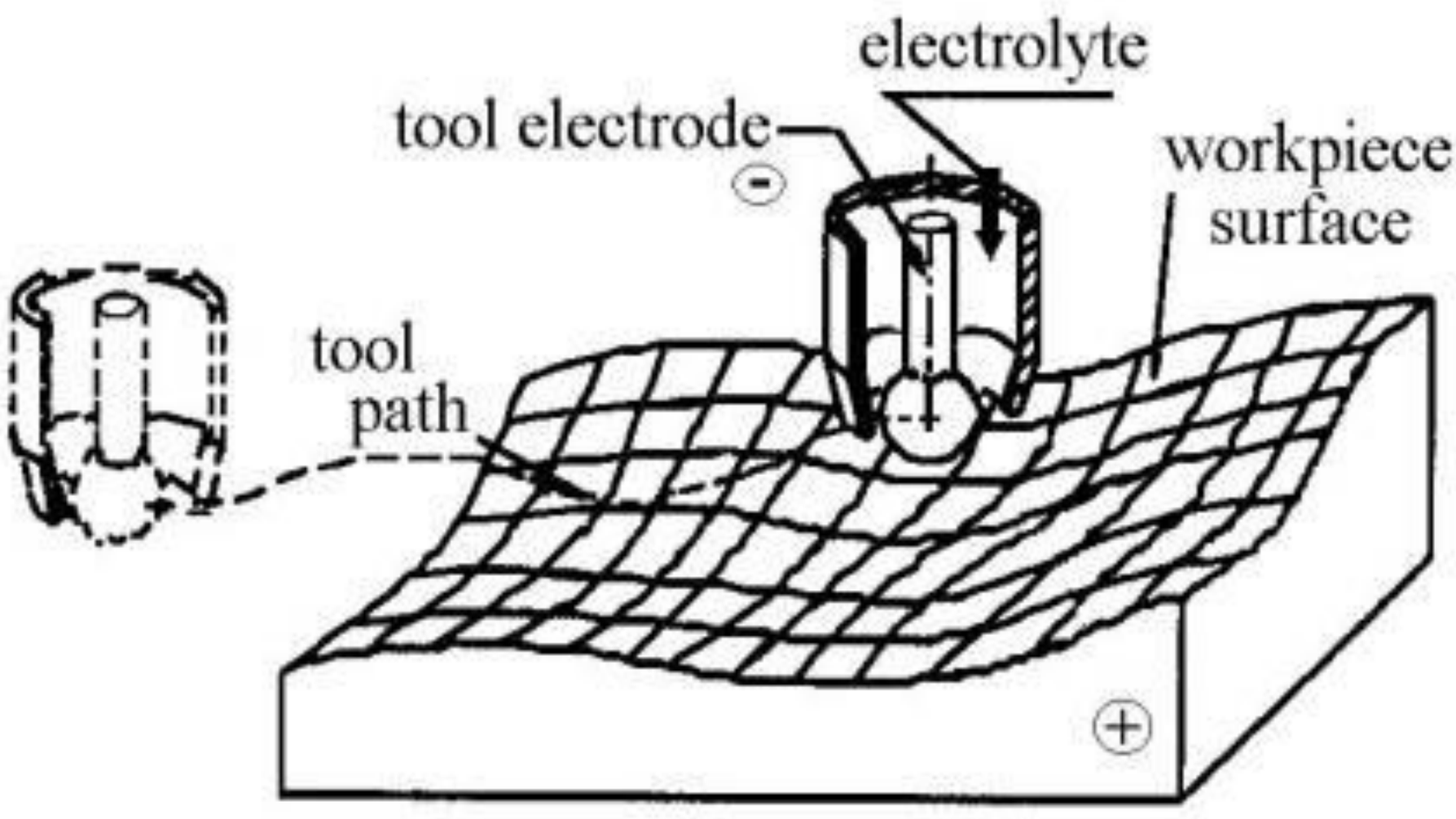
Schematic illustration of the electro-chemical machining process

It removes material by anodic dissolution with a rapidly flowing electrolyte

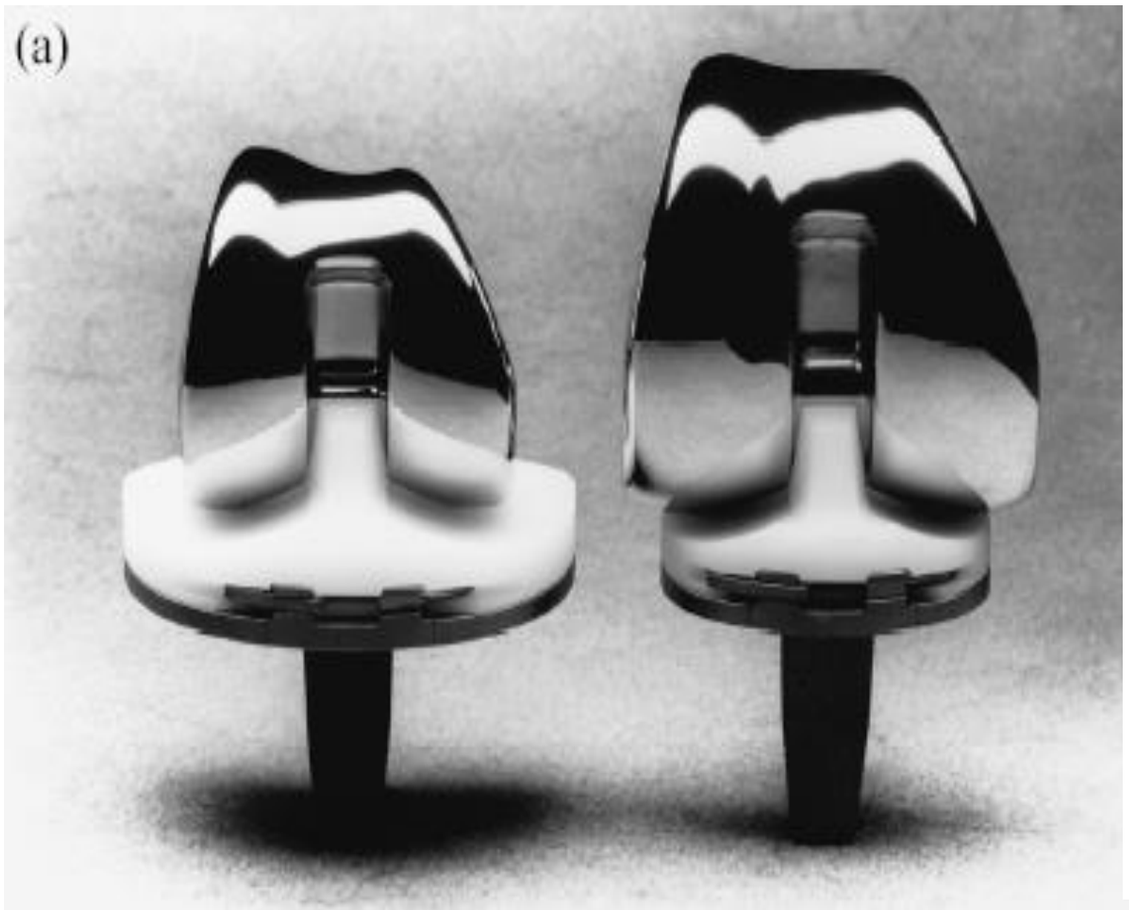
- This process is reversal of the electro-plating
- Electrolyte acts as current carrier
- High rate of electrolyte movement in tool work piece gap washes metal ions away from the workpiece (*ANODE*)
- This is washed just before they have a chance to plate on the tool (*CATHODE*)
- Shaped tool made of brass, copper, bronze, or stainless steel
- Electrolyte is pumped at a high rate through the passages in the tool
- Machines having current capacities as high as 40.000 A and as low as 5 A are available

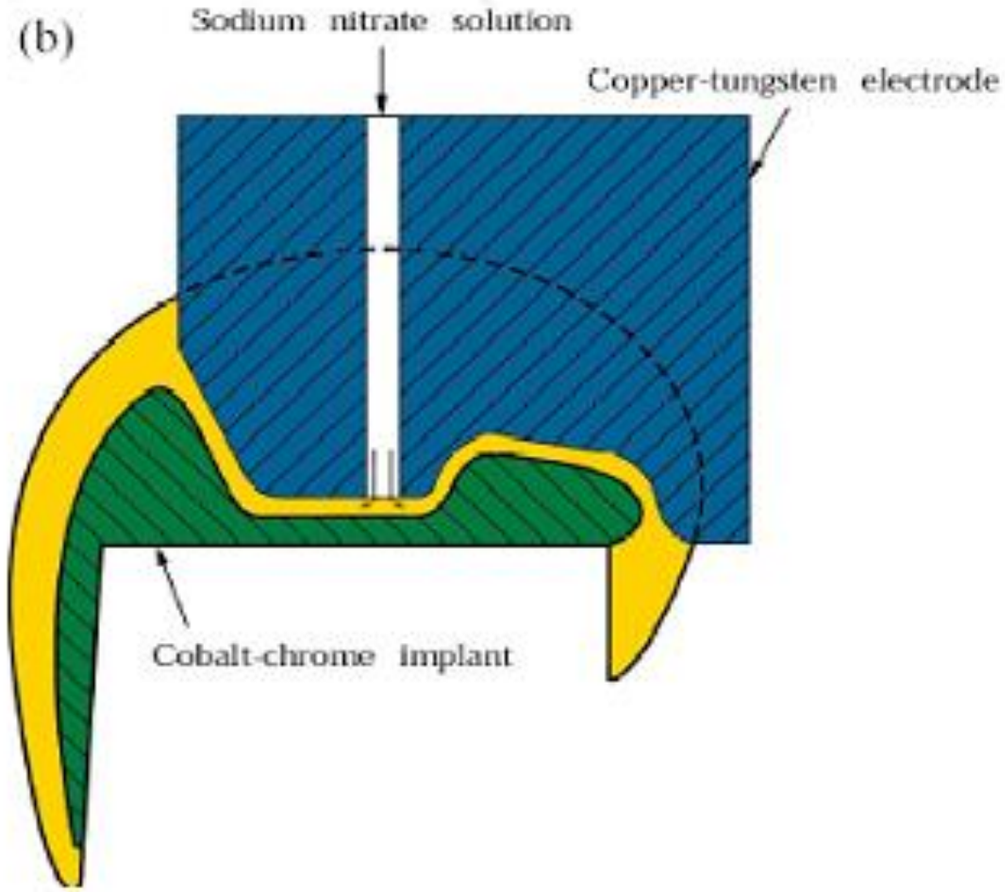
Electro-chemical machining /2

The tool may also be connected to a CNC machine to produce even more complex shapes with a single tool (ex: *die-sinking*).



Implants made by electro-chemical machining





Characteristics of electro-chemical machining

$$MRR = CI\eta$$

where C=1-2 (mm^3/A-min) for pure metals depends on valence; the higher the valence, the lower is its value

$$f = \frac{MRR}{A_0}$$

where f=feed rate (mm/min) of the electrode inside the workpiece when working a cavity of uniform cross-section A_0

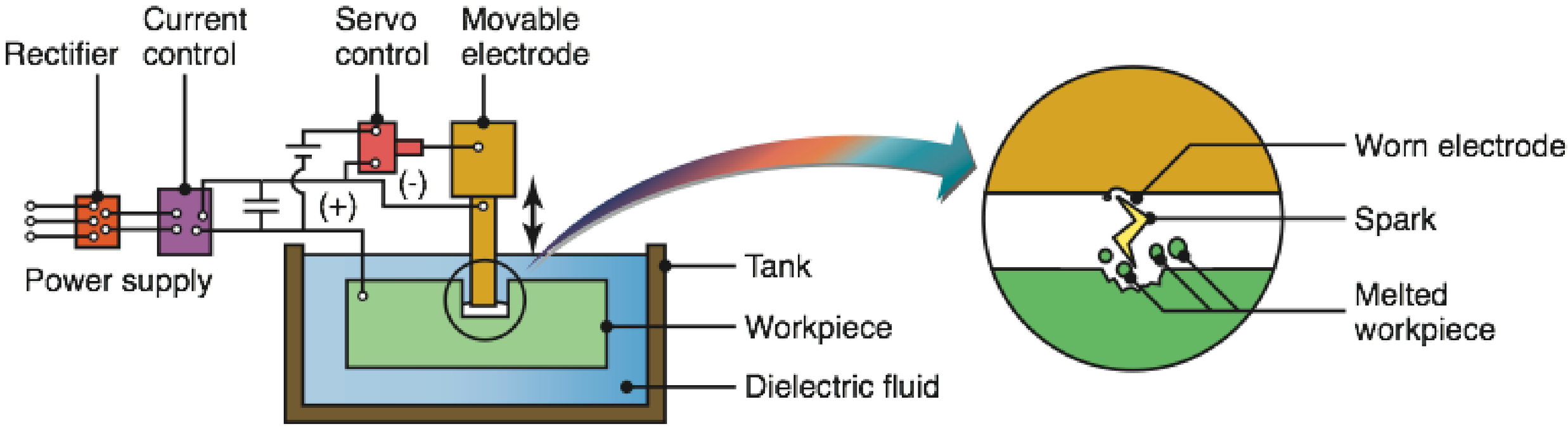
Advantages

- Materials of any hardness can be cut
- No physical contact with the workpiece -> no mechanical or thermal stresses generated, making it good for delicate parts
- Long tool life
- No edge burrs
- Holes completed in one “pass”

Disadvantages

- Workpiece must be electrically conductive
- Capital equipment expensive, particularly the electrolyte pumping and cleaning systems
- Form tooling cost can be high, particularly where 360° cutting is required

Electro-discharge machining /1



Schematic illustration of the electro-discharge machining process:

It cuts metal by discharging electric current stored in a capacitor bank across a thin gap between the tool (cathode) and the workpiece (anode)

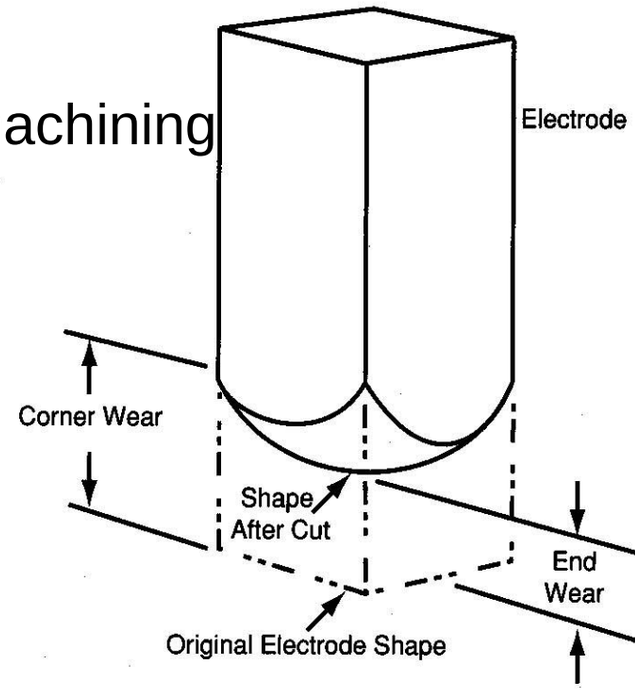
Electro-discharge machining /2

DIELECTRIC FLUID: usually mineral oils

1. Acts as insulator until the potential is sufficiently high
2. Acts as a flushing medium and carries away the debris in the gap
3. Provides a cooling medium

ELECTRODE: usually graphite

1. Are shaped by forming, casting, powder metallurgy or machining
2. As small as 0.1 mm in diameter
3. Tool wear important factor
4. Gap between tool and workpiece (overcut) is critical: to be kept a constant gap



Wear rate of the electrode (mm^3/min)

$$W = 1.1x10^3 IT_t^{-2.38}$$

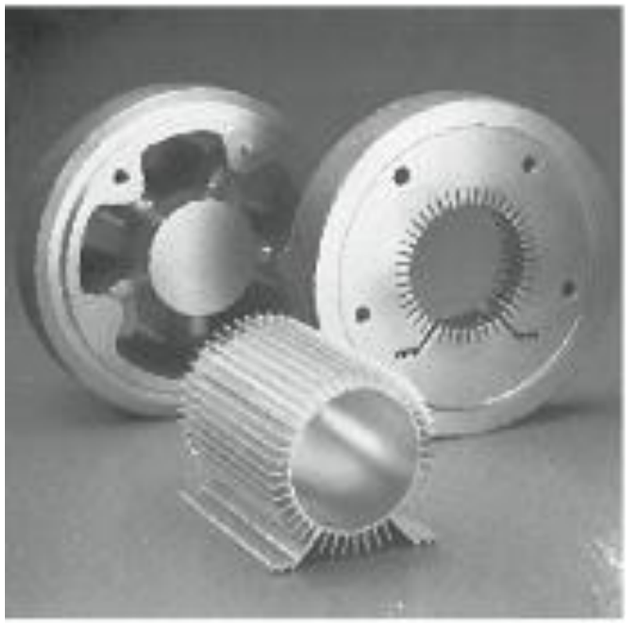
where T_t (° C) is the melting temperature of the electrode material

Wear ratio of the workpiece to electrode

$$R = 2.25T_r^{-2.38}$$

where T_r is the ratio of workpiece to electrode melting temperatures

Parts made by electro-discharge machining



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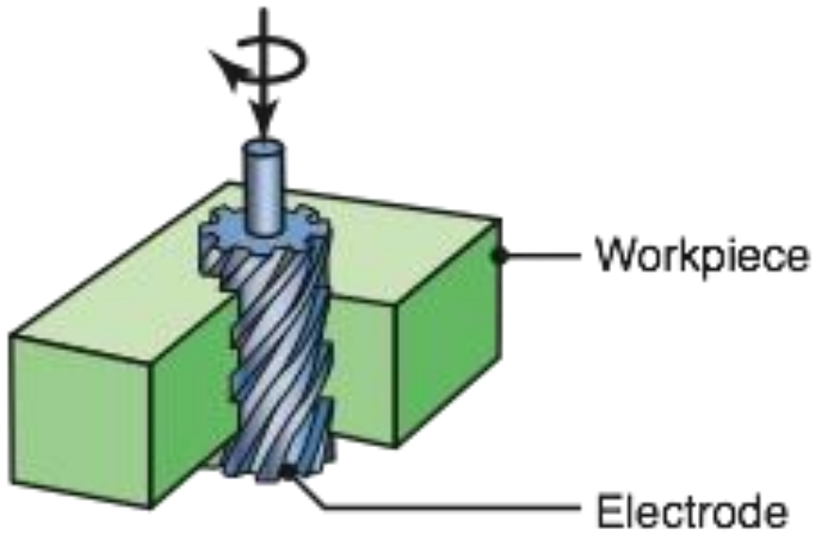

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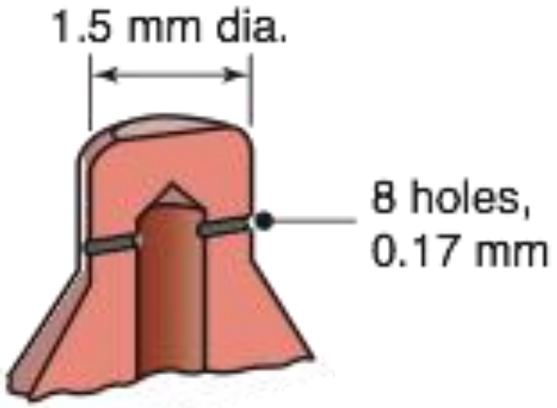


(c)

(a) Examples of cavities produced by the electrical-discharge-machining process, using shaped electrodes. The two round parts (rear) are the set of dies for extruding the aluminum piece shown in front. *Source*: Courtesy of AGIE USA Ltd. (b) A spiral cavity produced by a rotating electrode. *Source*: *American Machinist*. (c) Holes in a fuel-injection nozzle made by electrical-discharge machining. Material: Heat-treated steel.

Characteristics of electro-discharge machining

$$MRR = 4x10^{4} IT_{m}^{-1.23}$$

where MRR (mm^3/min), I is the current intensity (A), T_m is the workpiece melting temperature (° C)

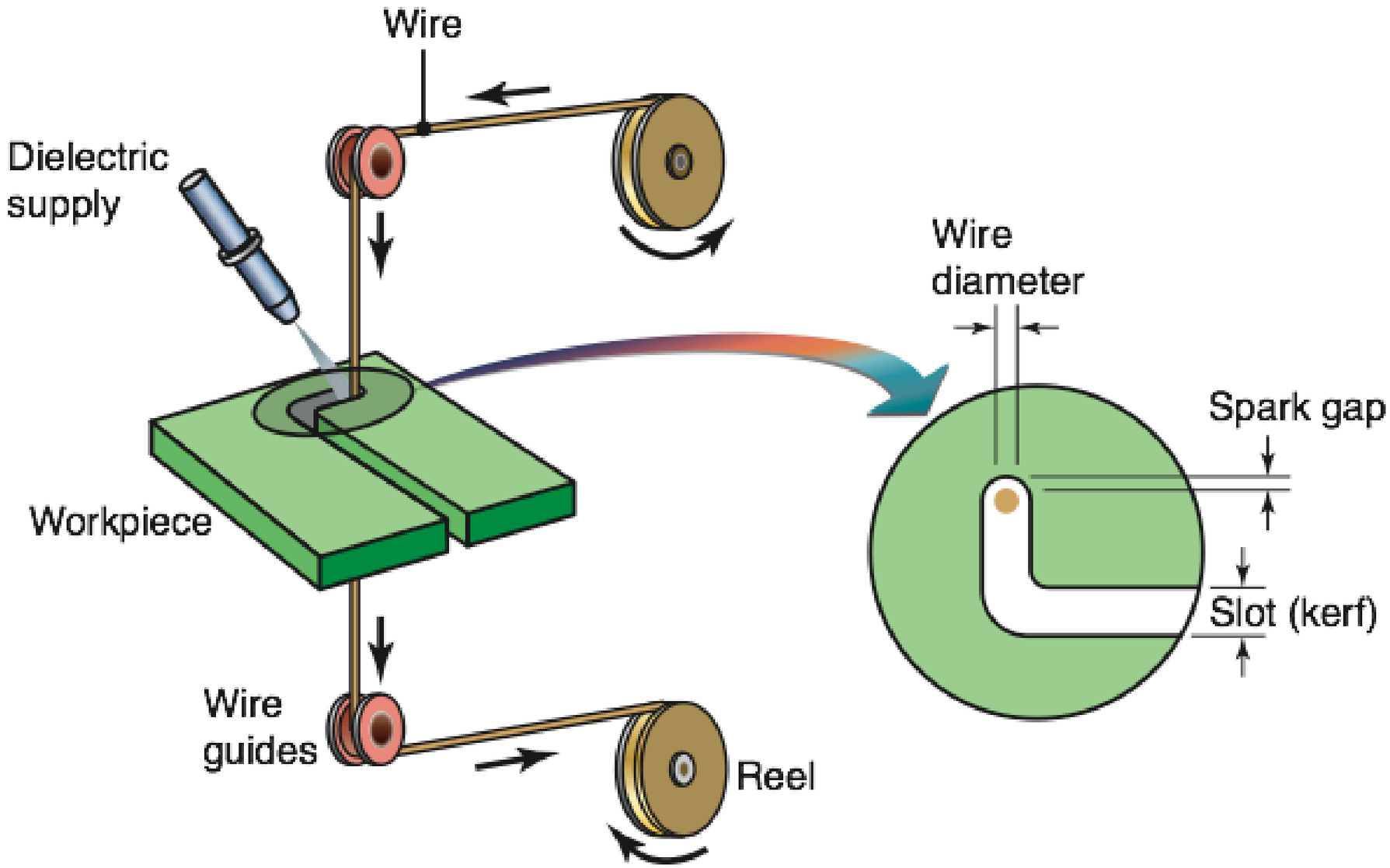
Advantages

- Materials of any hardness can be cut
- High accuracy and good surface finish are possible
- No cutting forces involved
- Intricate-shaped cavities can be cut with modest tooling costs
- Holes completed in one “pass”

Disadvantages

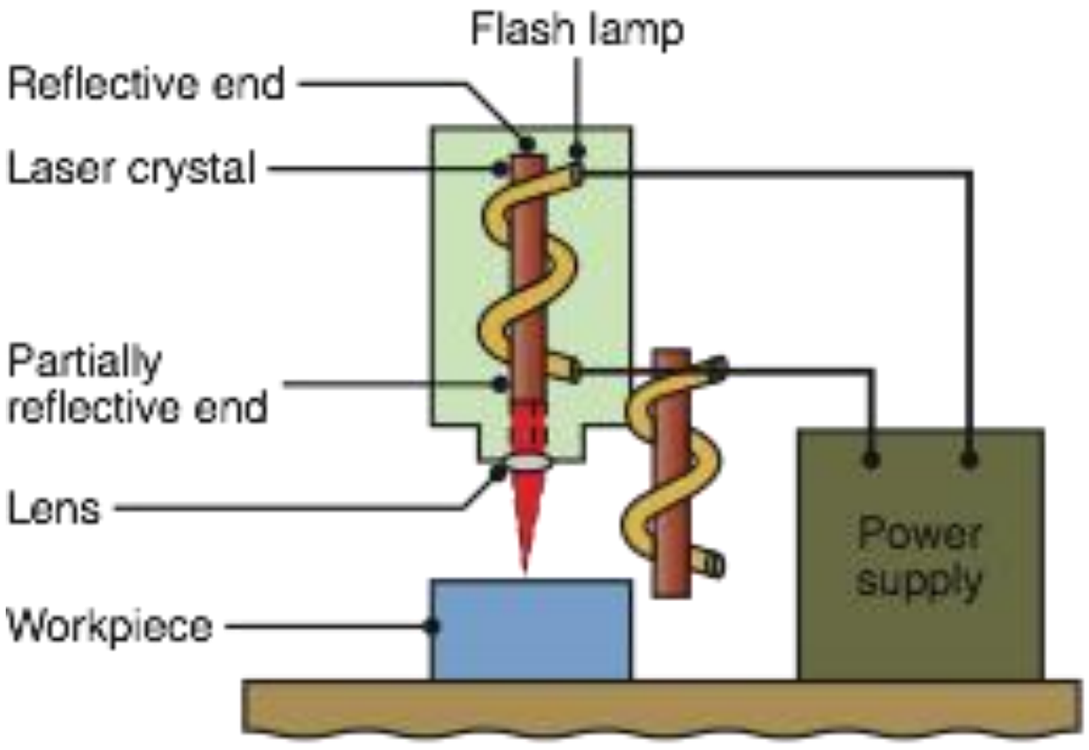
- Limited to electrically conductive materials
- Slow process, particularly if good surface finish and high accuracy are required (2-400 mm^3/min)
- Dielectric vapor can be dangerous
- Heat Affected Zone (HAZ) near cutting edges
- Die sinking tool life is limited

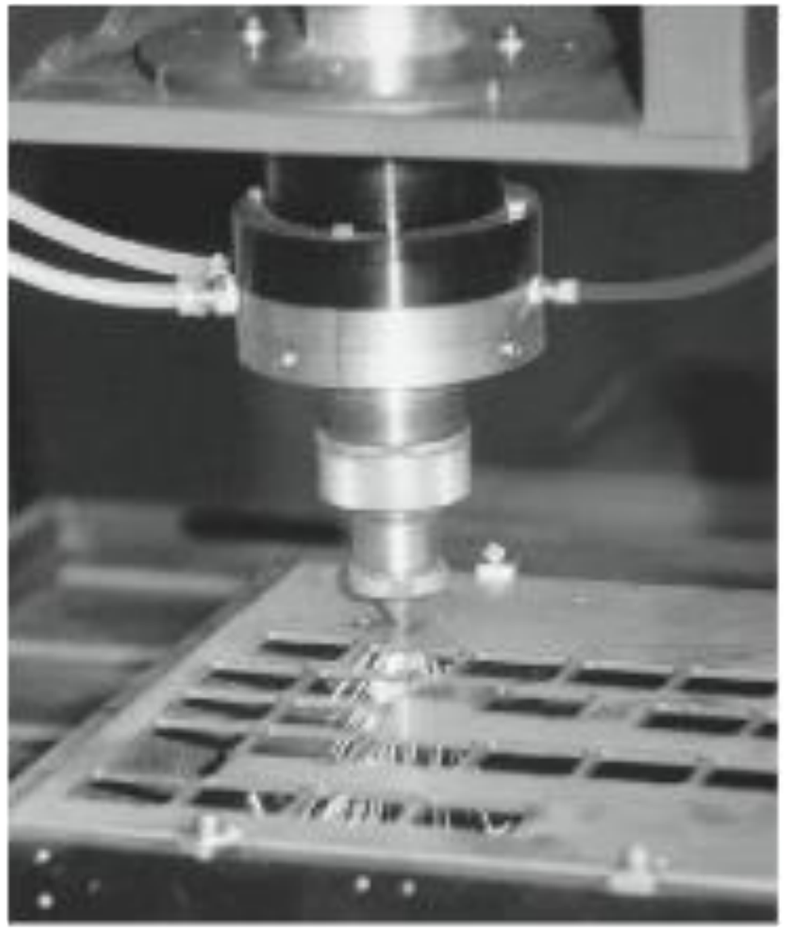
Wire electro-discharge machining



Schematic illustration of the wire EDM process. As much as 50 hours of machining can be performed with one reel of wire, which is then discarded.

Laser machining





Schematic illustration of the laser beam machining process:
A laser focuses optical energy on the workpiece surface; the highly focused, high-density energy melts/vaporizes portions of the workpiece in a controlled manner

Characteristics of laser machining

- High energy beam used to melt/vaporize the surface of the workpiece
- Used for drilling, profile cutting, and surface hardening

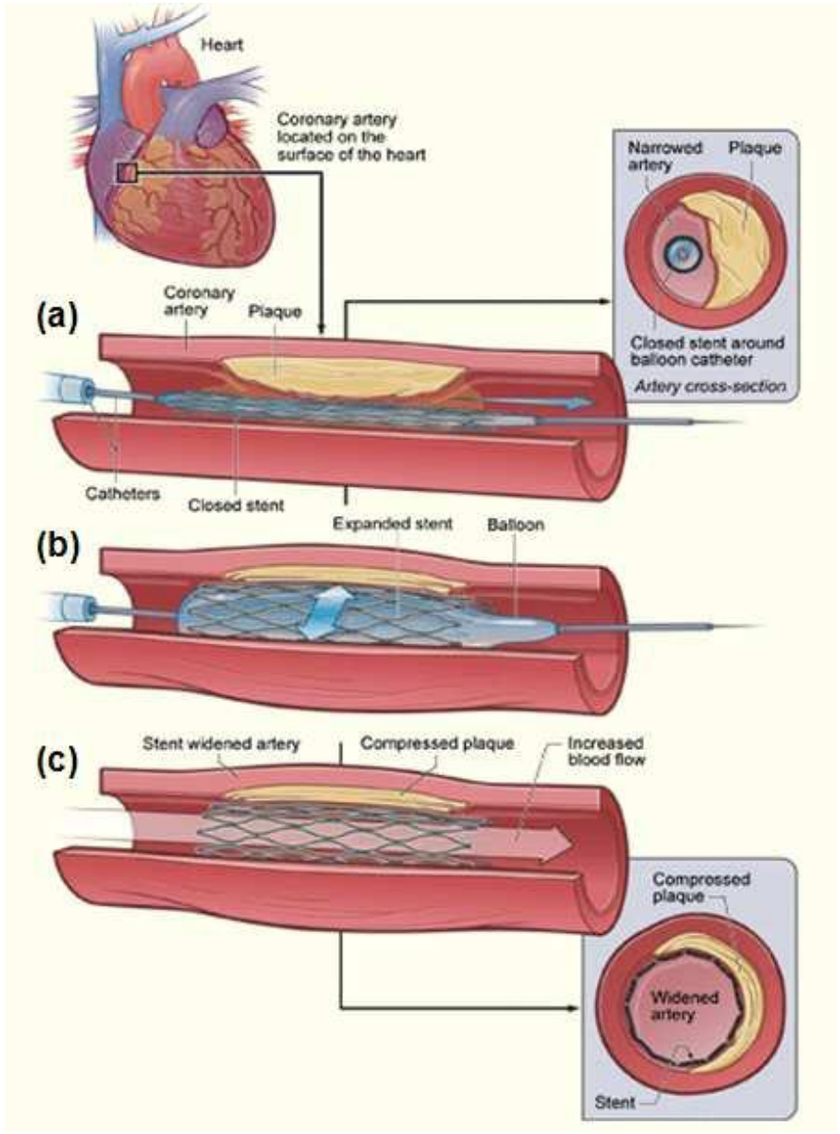
Advantages

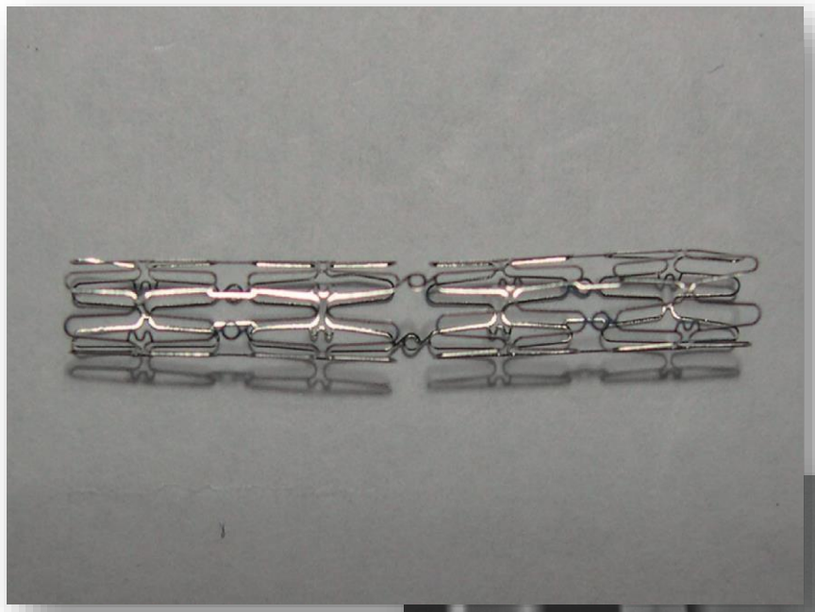
- Virtually any material can be cut
- 2D and 3D shapes can be cut
- Drilling holes having length/diameter ratio of up to 100:1 is possible
- No cutting forces are involved so that no mechanical stresses are imposed on the part
- High speed cutting possible with thin workpieces
- No consumable tooling needed
- Work area doesn’t need to be under vacuum as required with EBM

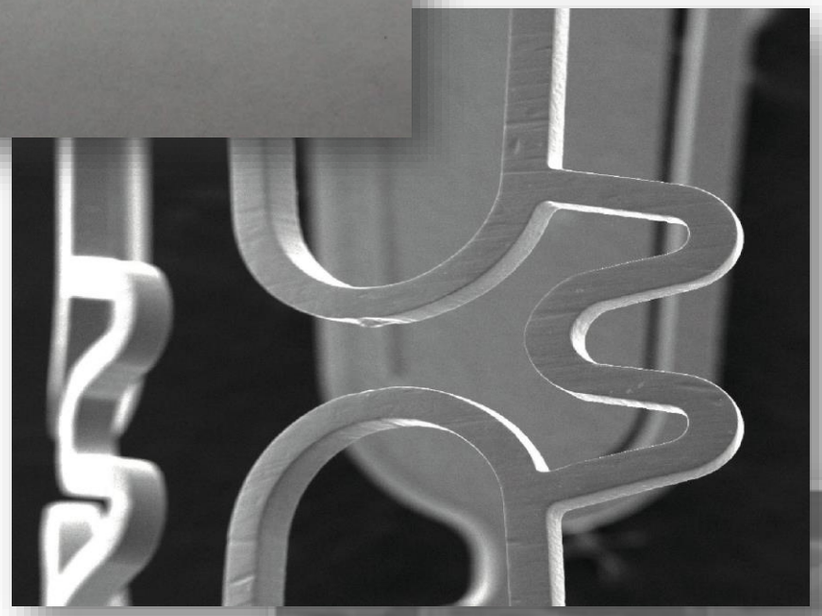
Disadvantages

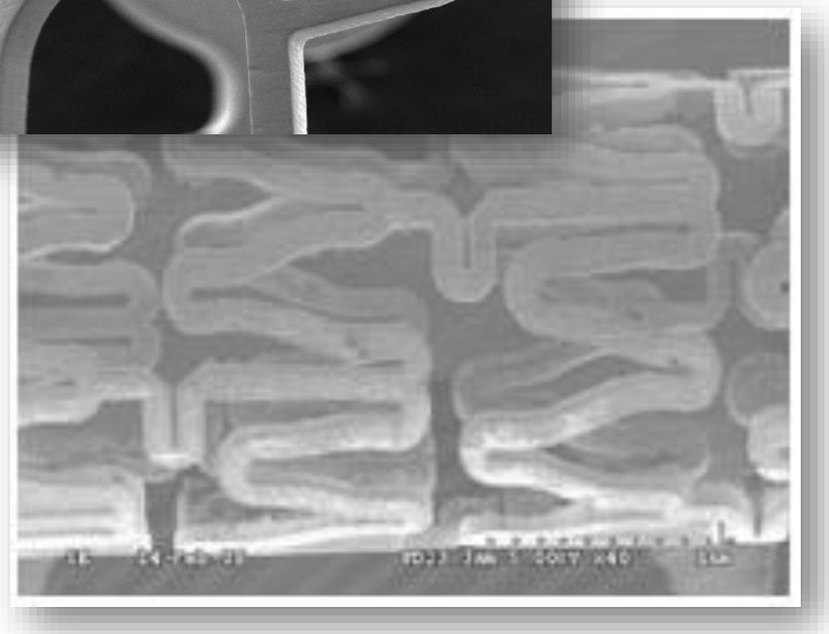
- Holes bigger than 1mm diameter are difficult to drill
- HAZ formed around cut surface edges
- Reflective surfaces difficult to machine

Laser cutting of stents

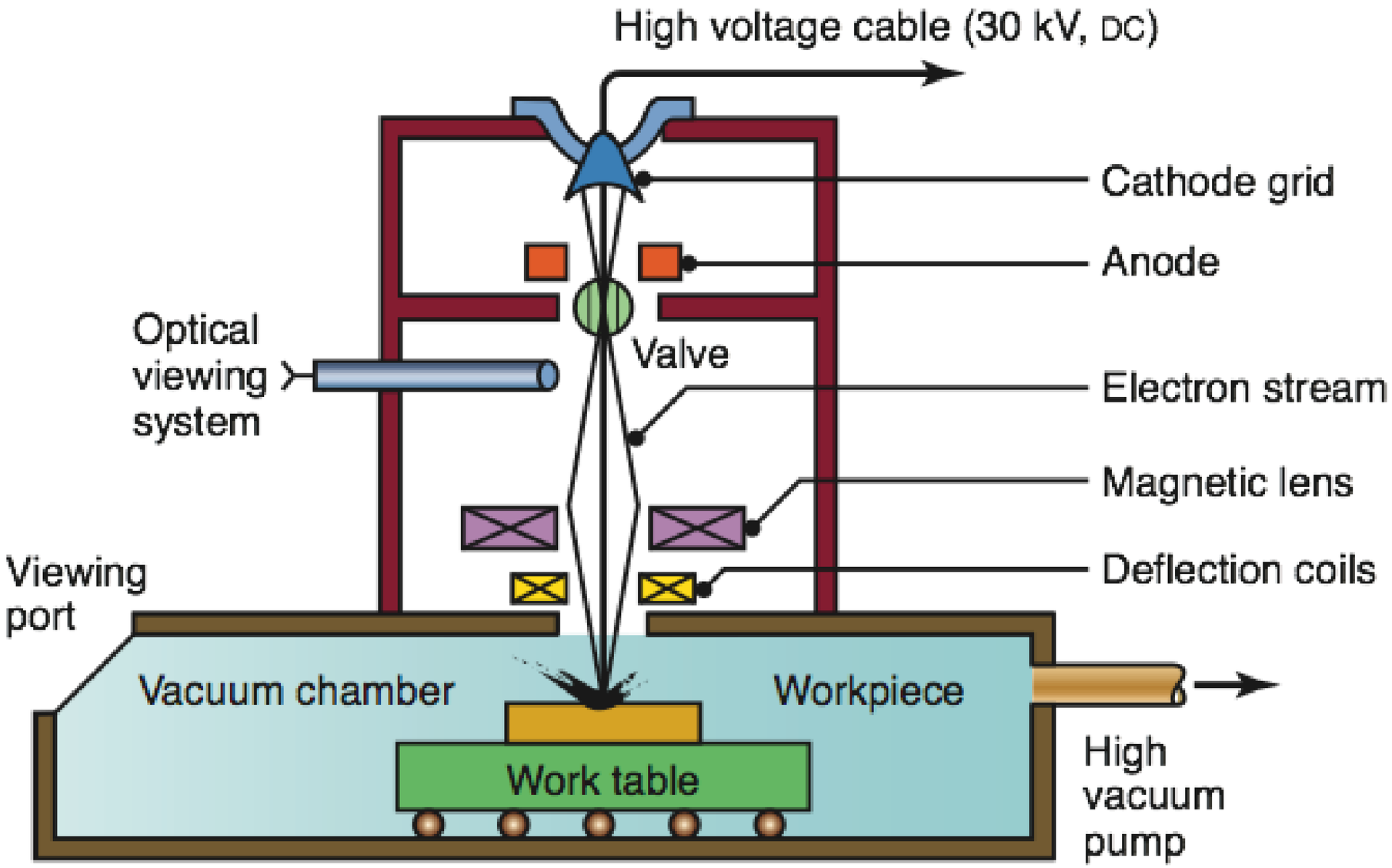








Electron beam machining



Schematic illustration of the electron beam machining process:
The source of energy is high-velocity electrons, which strike the workpiece surface and generate heat

Characteristics of electron beam machining

• Hole drilling and profile cutting is carried out by vaporizing the workpiece material with a high energy beam

Advantages

• Any material can be cut

• No cutting forces are involved so that no mechanical stresses are imposed on the part

• Exceptional drilling speeds possible with high position accuracy and form

• Extremely small kerf width when profiling so little material is wasted

Disadvantages

• Skilled labor is required

• A suitable backing material must be used

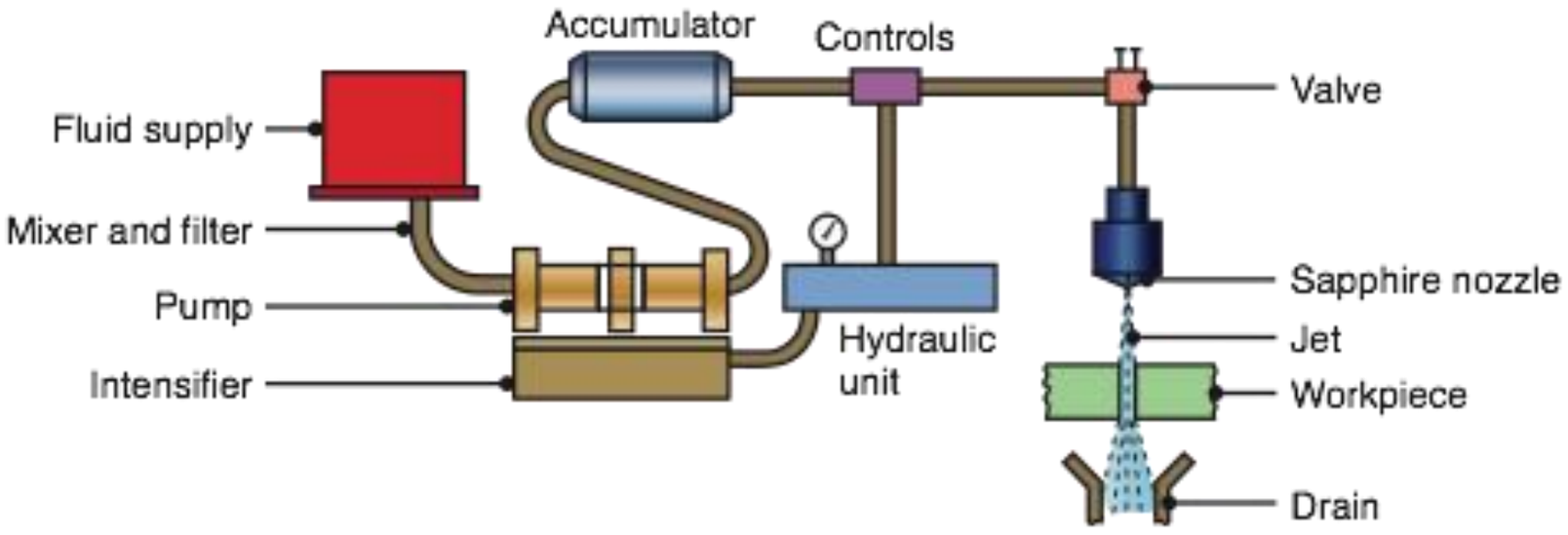
• Maximum thickness that can be cut about 10 mm

• Drilling length/diameter ratio up to 15:1

• Work area must be under a vacuum

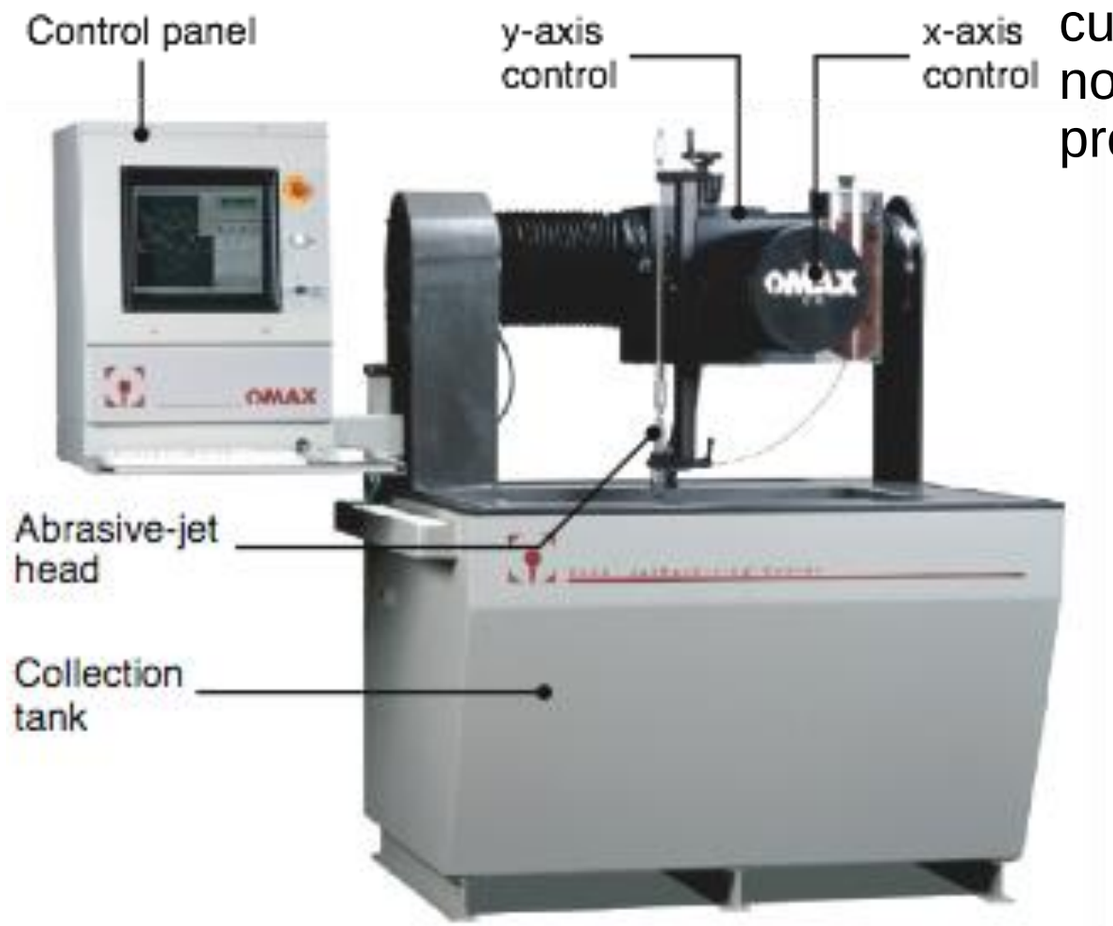
• Capital equipment cost is high

Water machining



(a)

(a) Schematic illustration of water-jet machining. (b) A computer-controlled, water-jet cutting machine cutting a granite plate. (c) Example of various nonmetallic parts produced by the water-jet cutting process.



Characteristics of water machining

- Water at extremely high pressure is fired at the surface to be cut
- For cutting metal, glass, etc. an abrasive powder is added to increase penetration power

Advantages

- Materials of any hardness can be cut, even food
- Cutting can be in any direction
- 3D cutting possible with CNC nozzle control
- No deburring is required
- No thermal stresses in the workpiece

Disadvantages

- Limited nozzle life, particularly when abrasives are used
- High capital cost of equipment
- Very noisy process because of supersonic nozzle velocities