NONTRADITIONAL MACHINING AND THERMAL CUTTING PROCESSES

- Mechanical Energy Processes
- Electrochemical Machining Processes
- Thermal Energy Processes
- Chemical Machining
- Application Considerations

Nontraditional Processes Defined

A group of processes that remove excess material by various techniques involving mechanical, thermal, electrical, or chemical energy (or combinations of these energies) but do not use a sharp cutting tool in the conventional sense

- Developed since World War II in response to new and unusual machining requirements that could not be satisfied by conventional methods

Why Nontraditional Processes are Important

- Need to machine newly developed metals and non-metals with special properties that make them difficult or impossible to machine by conventional methods
- Need for unusual and/or complex part geometries that cannot easily be accomplished by conventional machining
- Need to avoid surface damage that often accompanies conventional machining

Classification of Nontraditional Processes by Type of Energy Used

- *Mechanical* - erosion of work material by a high velocity stream of abrasives or fluid (or both) is the typical form of mechanical action
- *Electrical* - electrochemical energy to remove material (reverse of electroplating)
- *Thermal* – thermal energy usually applied to small portion of work surface, causing that portion to be removed by fusion and/or vaporization
- *Chemical* – chemical etchants selectively remove material from portions of workpart, while other portions are protected by a mask

Mechanical Energy Processes

- Ultrasonic machining
- Water jet cutting
- Abrasive water jet cutting
- Abrasive jet machining

Ultrasonic Machining (USM)

Abrasives contained in a slurry are driven at high velocity against work by a tool vibrating at low amplitude and high frequency

- Tool oscillation is perpendicular to work surface
- Tool is fed slowly into work
- Shape of tool is formed in part

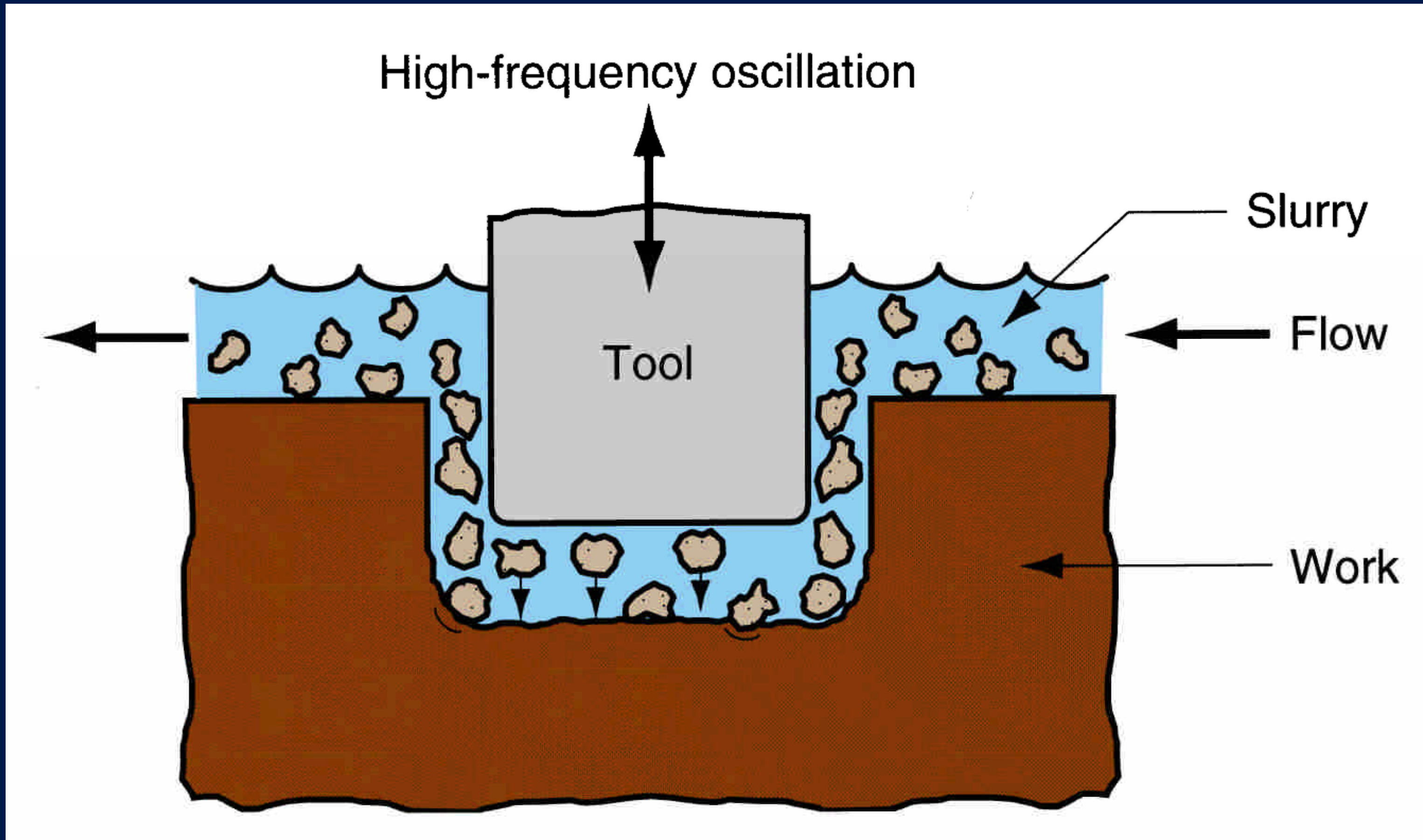

Figure 26.1 - Ultrasonic machining

USM Applications

- Hard, brittle work materials such as ceramics, glass, and carbides
- Also successful on certain metals, such as stainless steel and titanium
- Shapes include non-round holes, holes along a curved axis
- "Coining operations" - pattern on tool is imparted to a flat work surface

Water Jet Cutting (WJC)

Uses a fine, high pressure, high velocity stream of water directed at work surface for cutting

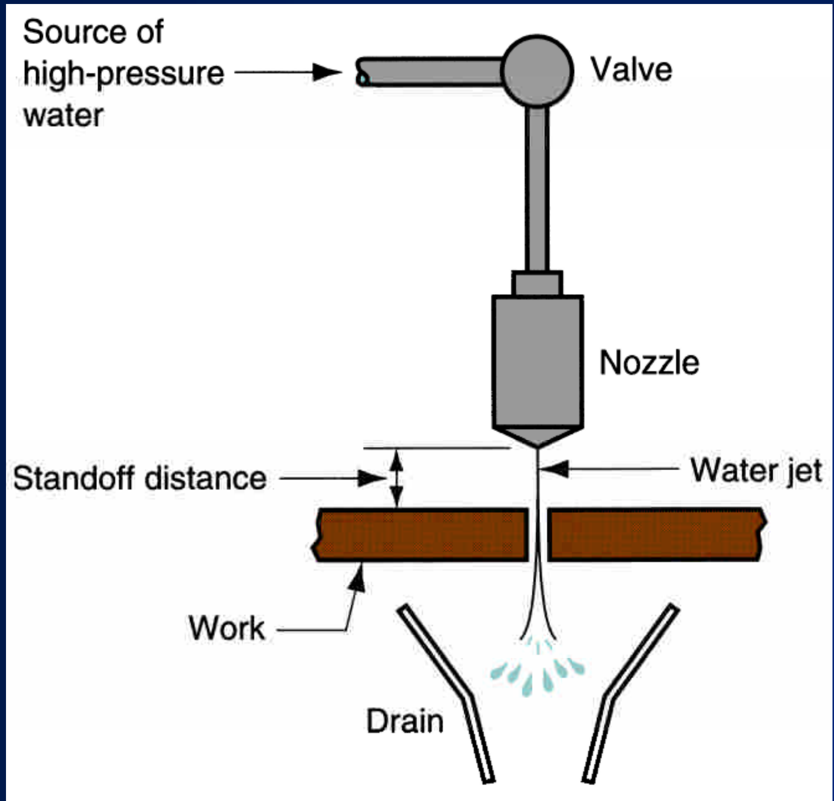

Figure 26.3 - Water jet cutting

WJC Applications

- Usually automated by CNC or industrial robots to manipulate nozzle along desired trajectory
- Used to cut narrow slits in flat stock such as plastic, textiles, composites, floor tile, carpet, leather, and cardboard
- Not suitable for brittle materials (e.g., glass)
- WJC advantages: no crushing or burning of work surface, minimum material loss, no environmental pollution, and ease of automation

Abrasive Water Jet Cutting (AWJC)

- When WJC is used on metals, abrasive particles must be added to jet stream usually
- Additional process parameters: abrasive type, grit size, and flow rate
  - Abrasives: aluminum oxide, silicon dioxide, and garnet (a silicate mineral)
  - Grit sizes range between 60 and 120
  - Grits added to water stream at about 0.25 kg/min (0.5 lb/min) after it exits nozzle

Abrasive Jet Machining (AJM)

- High velocity stream of gas containing small abrasive particles

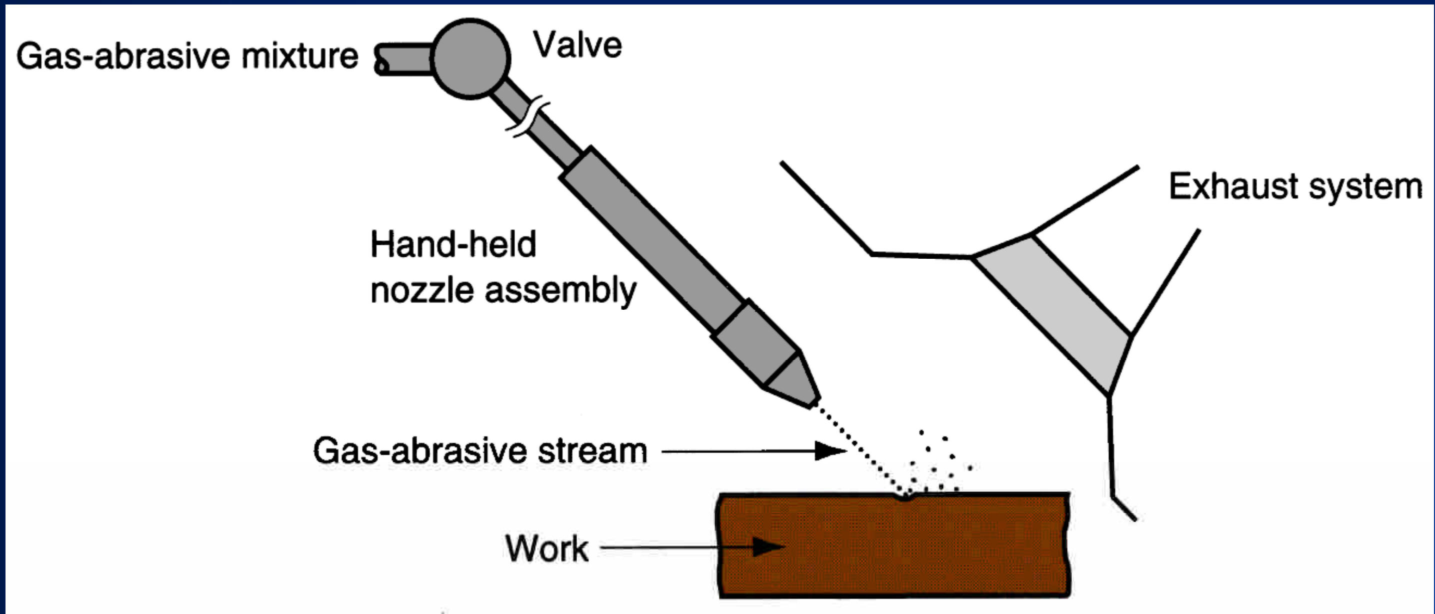

Figure 26.4 - Abrasive jet machining (AJM)

AJM Application Notes

- Usually performed manually by operator who directs nozzle
- Normally used as a finishing process rather than cutting process
- Applications: deburring, trimming and deflashing, cleaning, and polishing
- Work materials: thin flat stock of hard, brittle materials (e.g., glass, silicon, mica, ceramics)

Electrochemical Machining Processes

- Electrical energy used in combination with chemical reactions to remove material
- Reverse of electroplating
- Work material must be a conductor
- Processes:
  - Electrochemical machining (ECM)
  - Electrochemical deburring (ECD)
  - Electrochemical grinding (ECG)

Electrochemical Machining (ECM)

Material removal by anodic dissolution, using electrode (tool) in close proximity to the work but separated by a rapidly flowing electrolyte

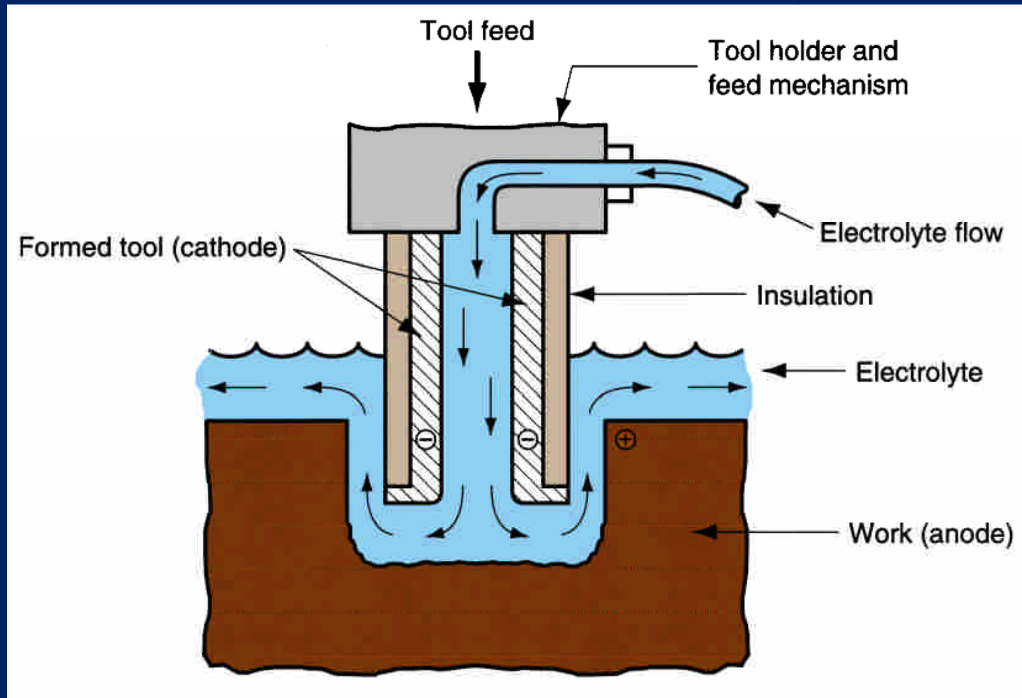

Figure 26.5 - Electrochemical machining (ECM)

ECM Operation

Material is deplated from *anode workpiece* (positive pole) and transported to a *cathode tool* (negative pole) in an electrolyte bath

- Electrolyte flows rapidly between the two poles to carry off deplated material, so it does not plate onto tool
- Electrode materials: Cu, brass, or stainless steel
- Tool has inverse shape of part
  - Tool size and shape must allow for the gap

Process Physics in ECM

Based on *Faraday's First Law*: amount of chemical change (amount of metal dissolved) is proportional to the quantity of electricity passed (current x time)

$$V = CIt$$

where V = volume of metal removed; C = specific removal rate which work material; I = current; and t time

ECM Applications

- Die sinking - irregular shapes and contours for forging dies, plastic molds, and other tools
- Multiple hole drilling - many holes can be drilled simultaneously with ECM
- Holes that are not round, since rotating drill is not used in ECM
- Deburring

Electrochemical Deburring (ECD)

Adaptation of ECM to remove burrs or round sharp corners on holes in metal parts produced by conventional through-hole drilling

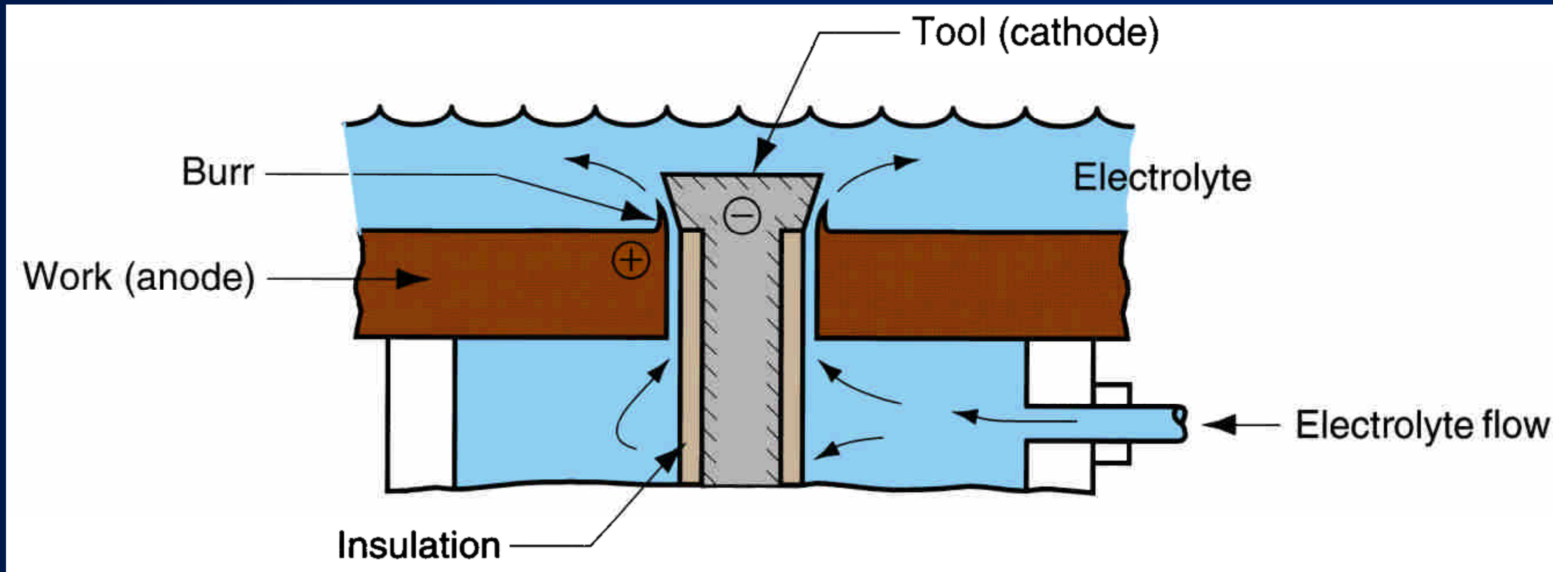

Figure 26.6 - Electrochemical deburring (ECD)

Electrochemical Grinding (ECG)

Special form of ECM in which a grinding wheel with conductive bond material is used to augment anodic dissolution of metal part surface

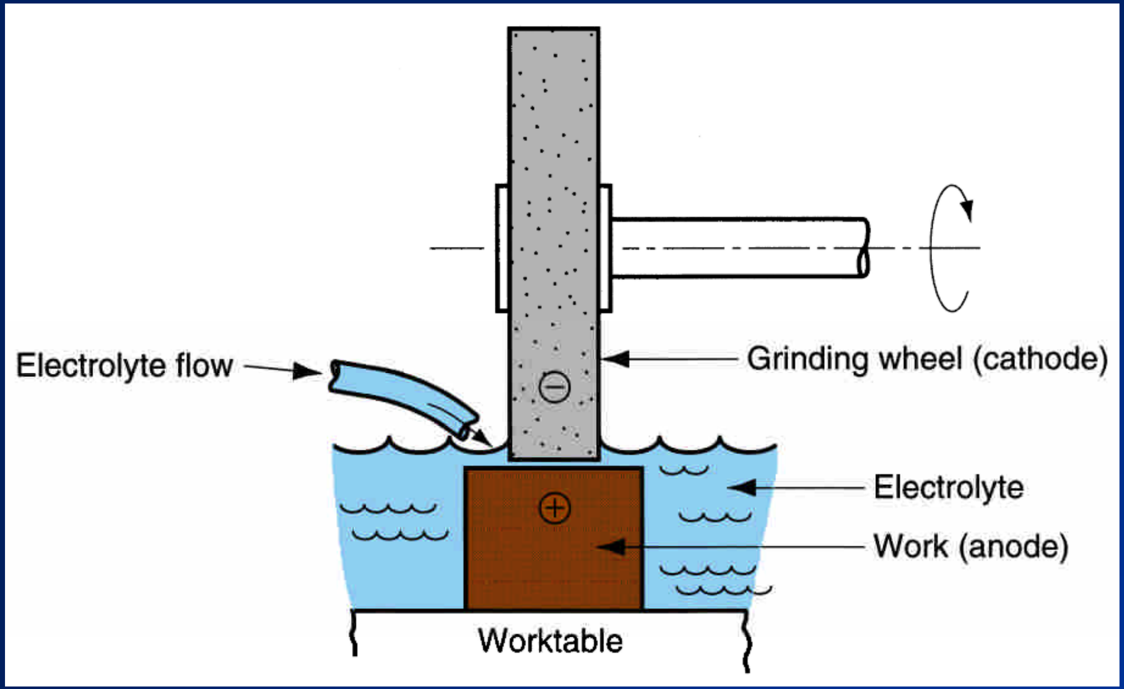

Figure 26.7 - Electrochemical grinding (ECG)

Applications and Advantages of ECG

- Applications:
  - Sharpening of cemented carbide tools
  - Grinding of surgical needles, other thin wall tubes, and fragile parts
- Advantages:
  - Deplating responsible for 95% of metal removal, and abrasive action removes remaining 5%
  - Because machining is mostly by electrochemical action, grinding wheel lasts much longer
    - Result: much higher grinding ratio, less frequent dressing

Thermal Energy Processes - Overview

- Very high local temperatures
  - Material is removed by fusion or vaporization
- Physical and metallurgical damage to the new work surface
- In some cases, resulting finish is so poor that subsequent processing is required

Thermal Energy Processes

- Electric discharge machining
- Electric discharge wire cutting
- Electron beam machining
- Laser beam machining
- Plasma arc machining
- Conventional thermal cutting processes

Electric Discharge Processes

Metal removal by a series of discrete electrical discharges (sparks) causing localized temperatures high enough to melt or vaporize the metal

- Can be used only on electrically conducting work materials
- Two main processes:
  1. Electric discharge machining
  2. Wire electric discharge machining

Electric Discharge Machining (EDM)

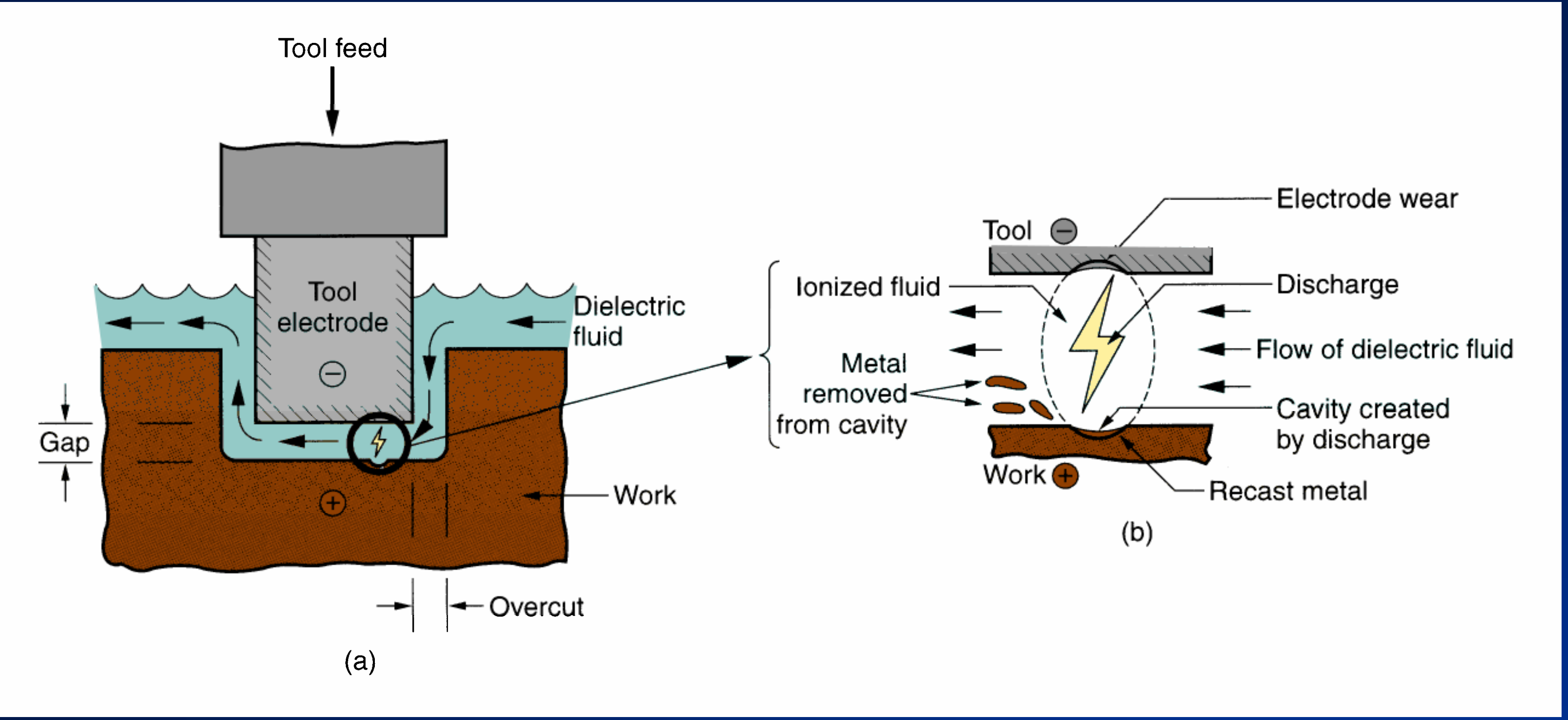

Figure 26.8 - Electric discharge machining (EDM): (a) overall setup, and (b) close-up view of gap, showing discharge and metal removal

EDM Operation

- One of the most widely used nontraditional processes
- Shape of finished work surface produced by a formed electrode tool
- Sparks occur across a small gap between tool and work
- Requires dielectric fluid, which creates a path for each discharge as fluid becomes ionized in the gap

Work Materials in EDM

- Only electrically conducting work materials
- Hardness and strength of the work material are not factors in EDM
- Material removal rate is related to melting point of work material

EDM Applications

- Tooling for many mechanical processes: molds for plastic injection molding, extrusion dies, wire drawing dies, forging and heading dies, and sheetmetal stamping dies
- Production parts: delicate parts not rigid enough to withstand conventional cutting forces, hole drilling where hole axis is at an acute angle to surface, and machining of hard and exotic metals

Wire EDM

Special form of EDM that uses small diameter wire as electrode to cut a narrow kerf in work

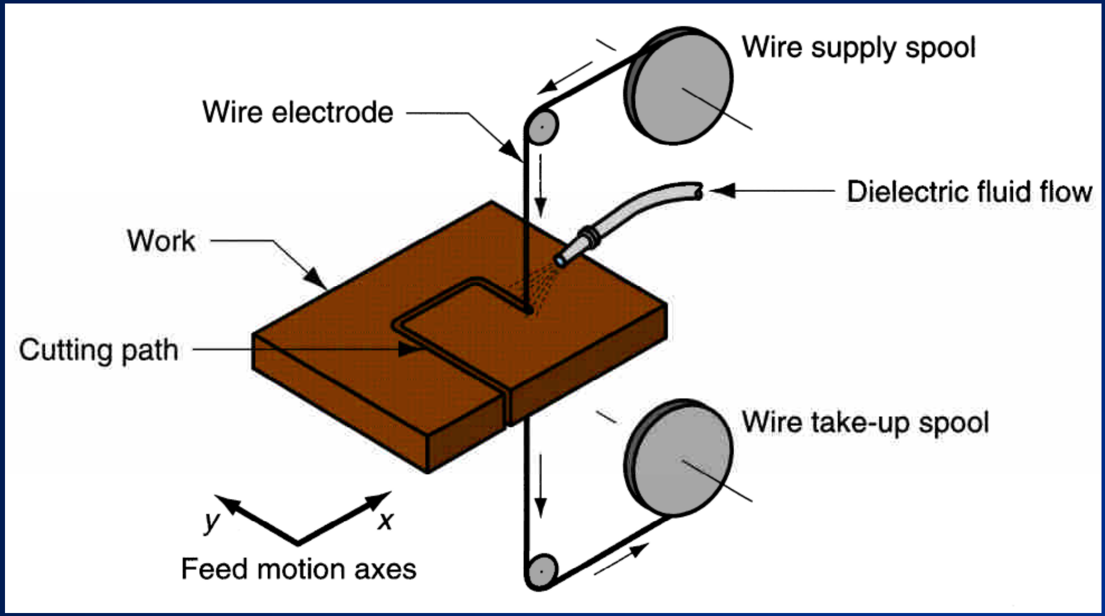

Figure 26.10 - Electric discharge wire cutting (EDWC), also called wire EDM

Operation of Wire EDM

- Work is fed slowly past wire along desired cutting path, like a bandsaw operation
- CNC used for motion control
- While cutting, wire is continuously advanced between supply spool and take-up spool to maintain a constant diameter
- Dielectric required, using nozzles directed at tool-work interface or submerging workpart

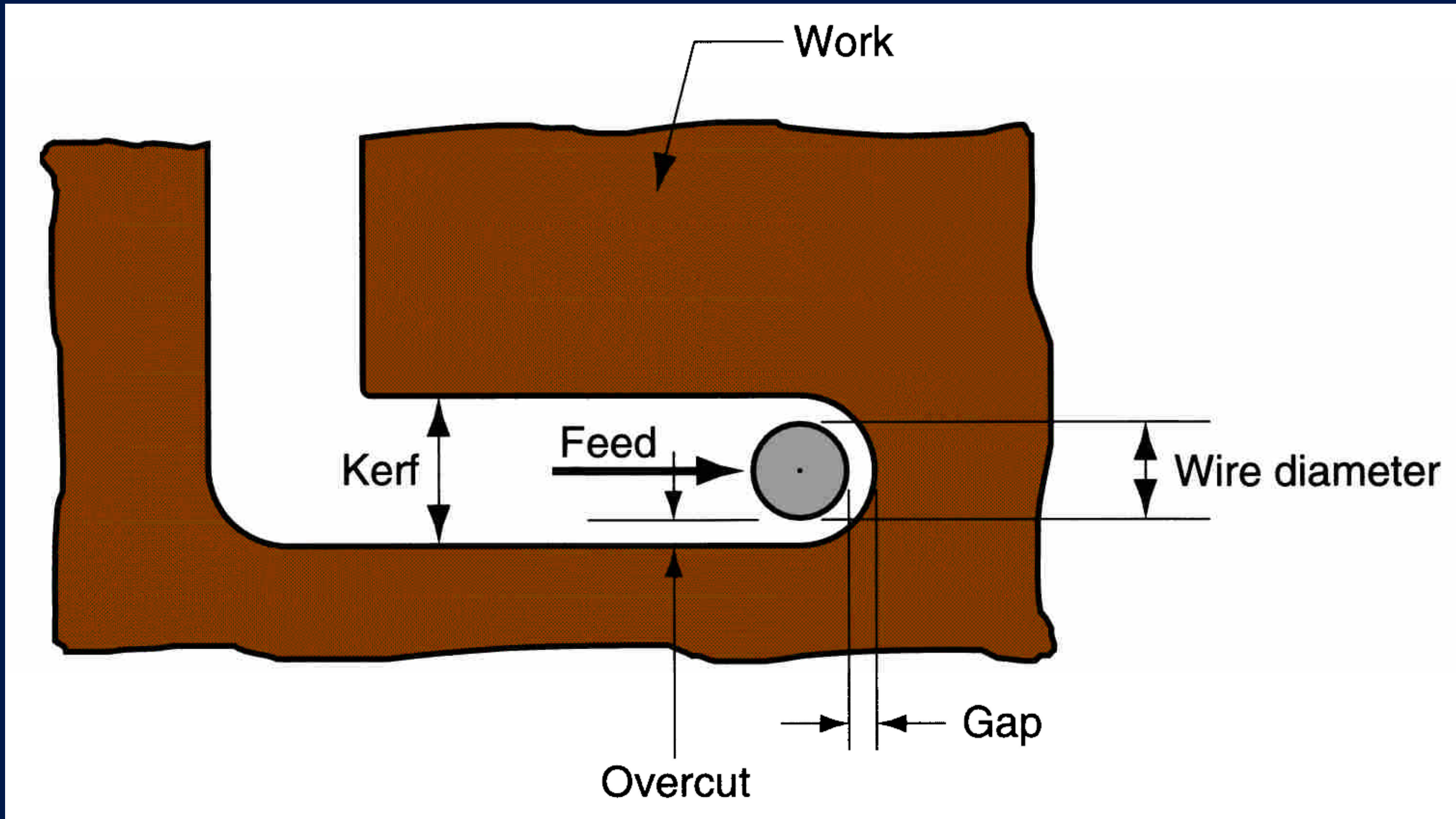

Figure 26.11 - Definition of kerf and overcut in electric discharge wire cutting

Wire EDM Applications

- Ideal for stamping die components
  - Since kerf is so narrow, it is often possible to fabricate punch and die in a single cut
- Other tools and parts with intricate outline shapes, such as lathe form tools, extrusion dies, and flat templates

Electron Beam Machining (EBM)

Uses high velocity stream of electrons focused on workpiece surface to remove material by melting and vaporization

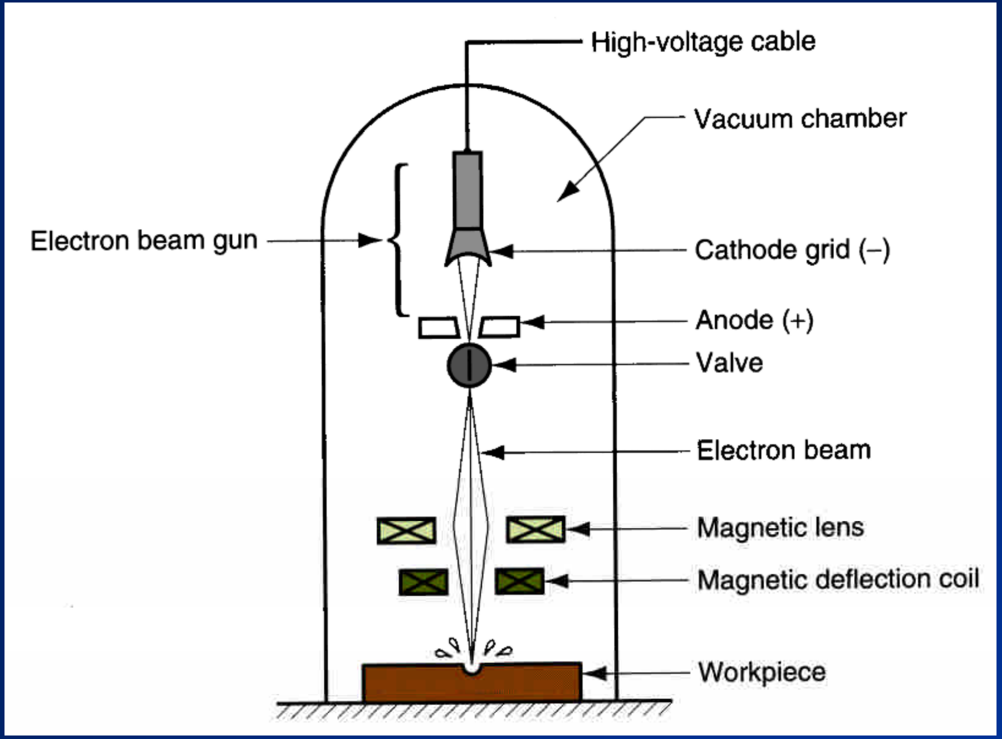

Figure 26.13 -

Electron beam machining (EBM)

EBM Operation

- EB gun accelerates a continuous stream of electrons to about 75% of light speed
- Beam is focused through electromagnetic lens, reducing diameter to as small as 0.025 mm (0.001 in)
- On impinging work surface, kinetic energy of electrons is converted to thermal energy of extremely high density which melts or vaporizes material in a very localized area

EBM Applications

- Works on any known material
- Ideal for micromachining
  - Drilling small diameter holes - down to 0.05 mm (0.002 in)
  - Cutting slots only about 0.025 mm (0.001 in.) wide
- Drilling holes with very high depth-to-diameter ratios
  - Ratios greater than 100:1

Laser Beam Machining (LBM)

Uses the light energy from a laser to remove material by vaporization and ablation

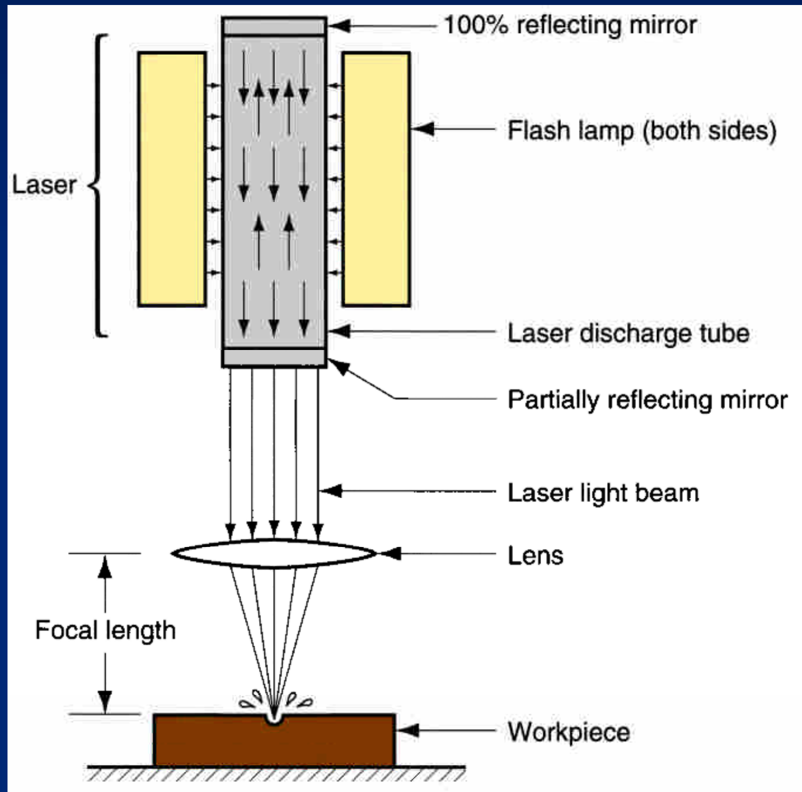

Figure 26.14 - Laser beam machining (LBM)

Laser

*L*ight *a*mplification by *s*timulated *e*mission of *r*adiation"

- A laser converts electrical energy into a highly coherent light beam with the following properties:
  - Monochromatic (theoretically, single wave length)
  - Highly collimated (light rays are almost perfectly parallel)
- These properties allow laser light to be focused, using optical lenses, onto a very small spot with resulting high power densities

LBM Applications

- Drilling, slitting, slotting, scribing, and marking operations
- Drilling small diameter holes - down to 0.025 mm (0.001 in)
- Generally used on thin stock
- Work materials: metals with high hardness and strength, soft metals, ceramics, glass and glass epoxy, plastics, rubber, cloth, and wood

Plasma Arc Cutting (PAC)

Uses a plasma stream operating at very high temperatures to cut metal by melting

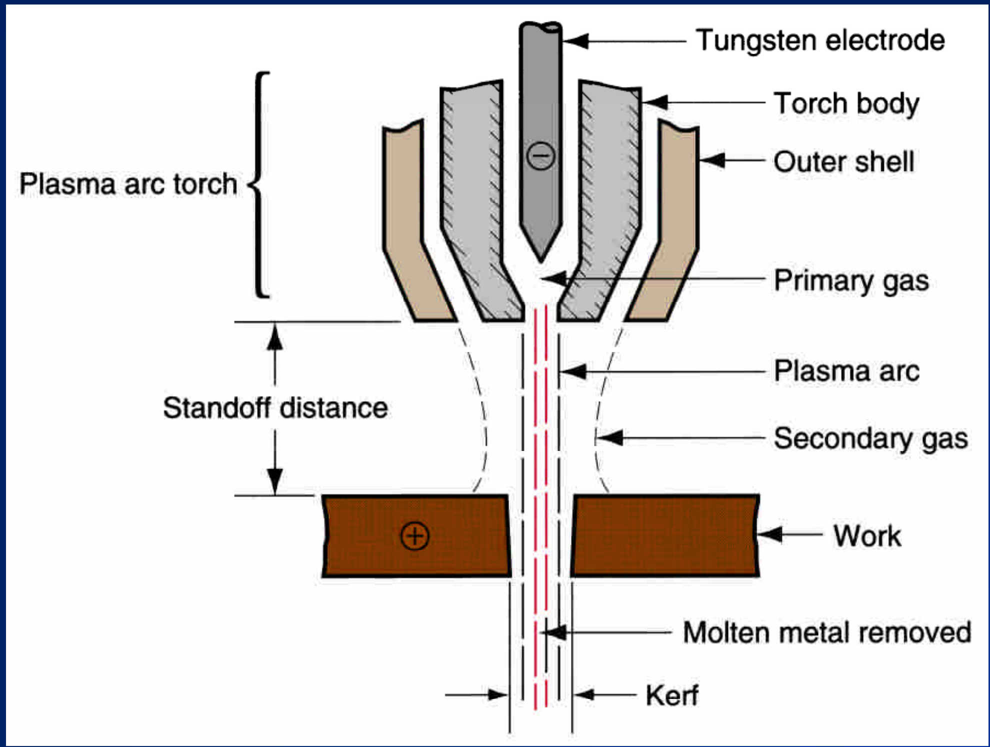

Figure 26.15 - Plasma arc cutting (PAC)

Operation of PAC

- *Plasma* = a superheated, electrically ionized gas
- PAC temperatures: 10,000°C to 14,000°C (18,000°F to 25,000°F)
- Plasma arc generated between electrode in torch and anode workpiece
- The plasma flows through water-cooled nozzle that constricts and directs stream to desired location

Applications of PAC

- Most applications of PAC involve cutting of flat metal sheets and plates
- Hole piercing and cutting along a defined path
- Can be operated by hand-held torch or automated by CNC
- Can cut any electrically conductive metal
- Most frequently cut metals: carbon steel, stainless steel, aluminum

Air Carbon Arc Cutting

Arc is generated between a carbon electrode and metallic work, and high-velocity air jet blows away melted portion of metal

- Can be used to form a kerf to sever a piece, or to gouge a cavity to prepare edges of plates for welding
- Work materials: cast iron, carbon steel, alloy steels, and various nonferrous alloys
- Spattering of molten metal is a hazard and a disadvantage

Other Arc Cutting Processes

- Not as widely used as plasma arc cutting and air carbon arc cutting:
  - Gas metal arc cutting
  - Shielded metal arc cutting
  - Gas tungsten arc cutting
  - Carbon arc cutting

Oxyfuel Cutting (OFC) Processes

Use heat of combustion of fuel gases combined with exothermic reaction of metal with oxygen

- Popularly known as *flame cutting*
- Cutting torch delivers a mixture of fuel gas and oxygen and directs a stream of oxygen to cutting region

Operation of OFC Processes

- Primary mechanism of material removal is chemical reaction of oxygen with base metal
  - Especially in cutting ferrous metals
- Purpose of oxyfuel combustion is to raise the temperature to support the reaction
- Commonly used to cut ferrous metal plates

OFC Fuels

- Acetylene (C_2H_2)
  - Highest flame temperature
  - Most widely used but hazardous
- MAPP (methylacetylene-propadiene - C_3H_4) -
- Propylene (C_3H_6)
- Propane (C_3H_8)

OFC Applications

- Performed manually or by machine
- Manual operation, examples of applications:
  - Repair work
  - Cutting scrap metal
  - Trimming risers from sand castings
- Machine flame cutting allows faster speeds and greater accuracies
  - Machine operation often CNC controlled to cut profiled shapes

Chemical Machining (CHM)

Material removal through contact with a strong chemical etchant

- Processes include:
  - Chemical milling
  - Chemical blanking
  - Chemical engraving
  - Photochemical machining
- All utilize the same mechanism of material removal

Steps in Chemical Machining

1. Cleaning - to insure uniform etching
2. Masking - a maskant (*resist*, chemically resistant to etchant) is applied to portions of work surface not to be etched
3. Etching - part is immersed in etchant which chemically attacks those portions of work surface that are not masked
4. Demasking - maskant is removed

Maskant in Chemical Machining

- Materials: neoprene, polyvinylchloride, polyethylene, and other polymers
- Masking accomplished by any of three methods:
  - Cut and peel
  - Photographic resist
  - Screen resist

Cut and Peel Maskant Method

- Maskant is applied over entire part by dipping, painting, or spraying
- After maskant hardens, it is cut by hand using a scribing knife and peeled away in areas of work surface to be etched
- Used for large workparts, low production quantities, and where accuracy is not a critical factor

Photographic Resist Method

- Masking materials contain photosensitive chemicals
- Maskant is applied to work surface and exposed to light through a negative image of areas to be etched
- These areas are then removed using photographic developing techniques
  - Remaining areas are vulnerable to etching
- Applications:
  - Small parts are produced in high quantities
  - Fabrication of integrated circuits and printed circuit cards

Screen Resist Method

- Maskant applied by “silk screening” methods
- Maskant is painted through a silk or stainless steel mesh containing stencil onto surface areas that are not to be etched
- Applications:
  - Between other two masking methods
  - Fabrication of printed circuit boards

Etchant

- Factors in selection of etchant:
  - Work material
  - Depth and rate of material removal
  - Surface finish requirements
- Etchant must also be matched with the type of maskant to insure that maskant material is not chemically attacked

Material Removal Rate in CHM

- Generally indicated as penetration rates, mm/min (in/min), since rate of chemical attack is directed into surface
- Penetration rate is unaffected by surface area
- Typical penetration between 0.020 and 0.050 mm/min (0.0008 and 0.002 in./min)

Undercut in CHM

Etching occurs downward and sideways under the maskant

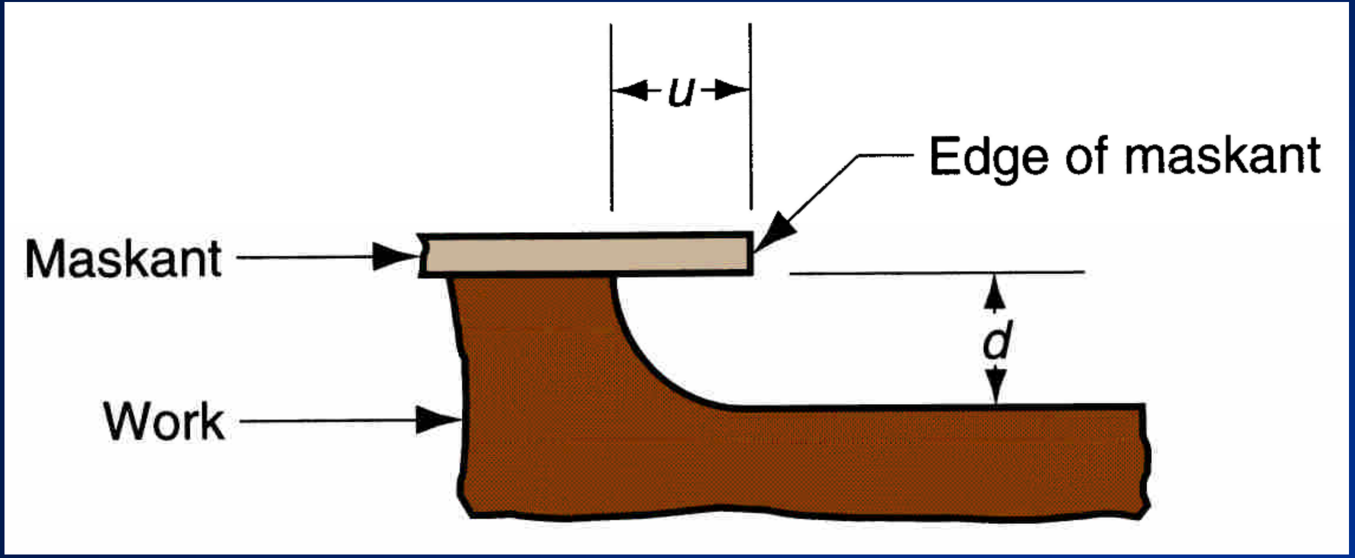

Figure 26.16 - Undercut in chemical machining

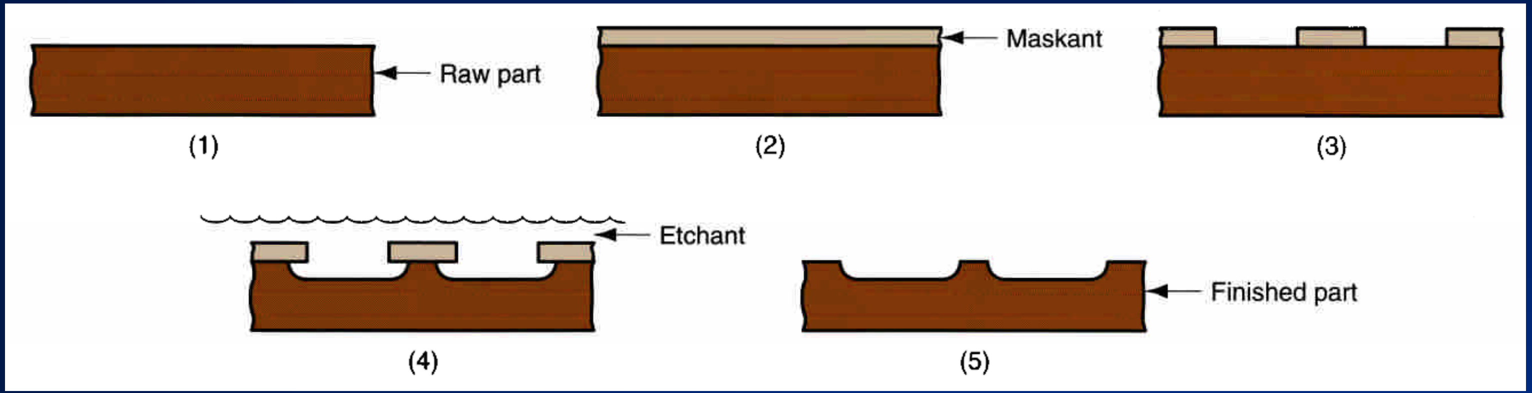

Figure 26.17 ‑ Sequence of processing steps in chemical milling: (1) clean raw part, (2) apply maskant, (3) scribe, cut, and peel the maskant from areas to be etched, (4) etch, and (5) remove maskant and clean to yield finished part

Applications of Chemical Milling

- Remove material from aircraft wing and fuselage panels for weight reduction
- Applicable to large parts where substantial amounts of metal are removed
- Cut and peel maskant method is used

Chemical Blanking

Uses chemical erosion to cut very thin sheetmetal parts - down to 0.025 mm (0.001 in) thick and/or for intricate cutting patterns

- Conventional punch and die does not work because stamping forces damage the thin sheetmetal, or tooling cost is prohibitive, or both
- Maskant methods are either photoresist or screen resist

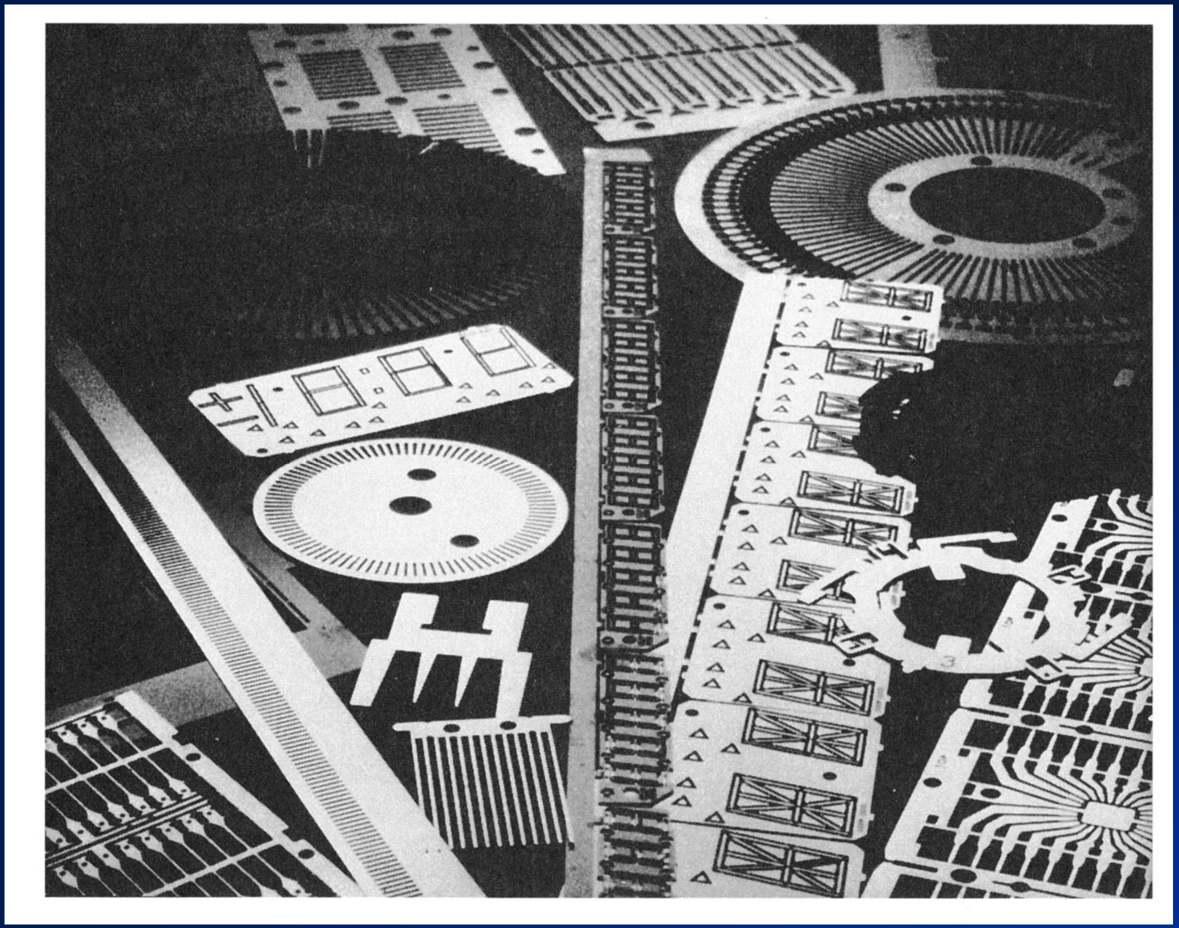

Figure 26.19 - Parts made by chemical blanking (courtesy Buckbee- Mears St. Paul)

Photochemical Machining (PCM)

- Uses photoresist masking method
- Applies to chemical blanking and chemical engraving when photographic resist method is used
- Used extensively in the electronics industry to produce intricate circuit designs on semiconductor wafers
- Also used in printed circuit board fabrication

Workpart Geometry Features Possible with Nontraditional Processes

- Very small holes
- Holes with large depth-to-diameter ratios
- Holes that are not round
- Narrow slots in slabs and plates
- Micromachining
- Shallow pockets and surface details in flat parts
- Special contoured shapes for mold and die applications

Work Materials

- As a group the nontraditional processes can be applied to metals and non-metals
  - However, certain processes are not suited to certain work materials
- Several processes can be used on metals but not nonmetals:
  - ECM
  - EDM and wire EDM
  - PAM