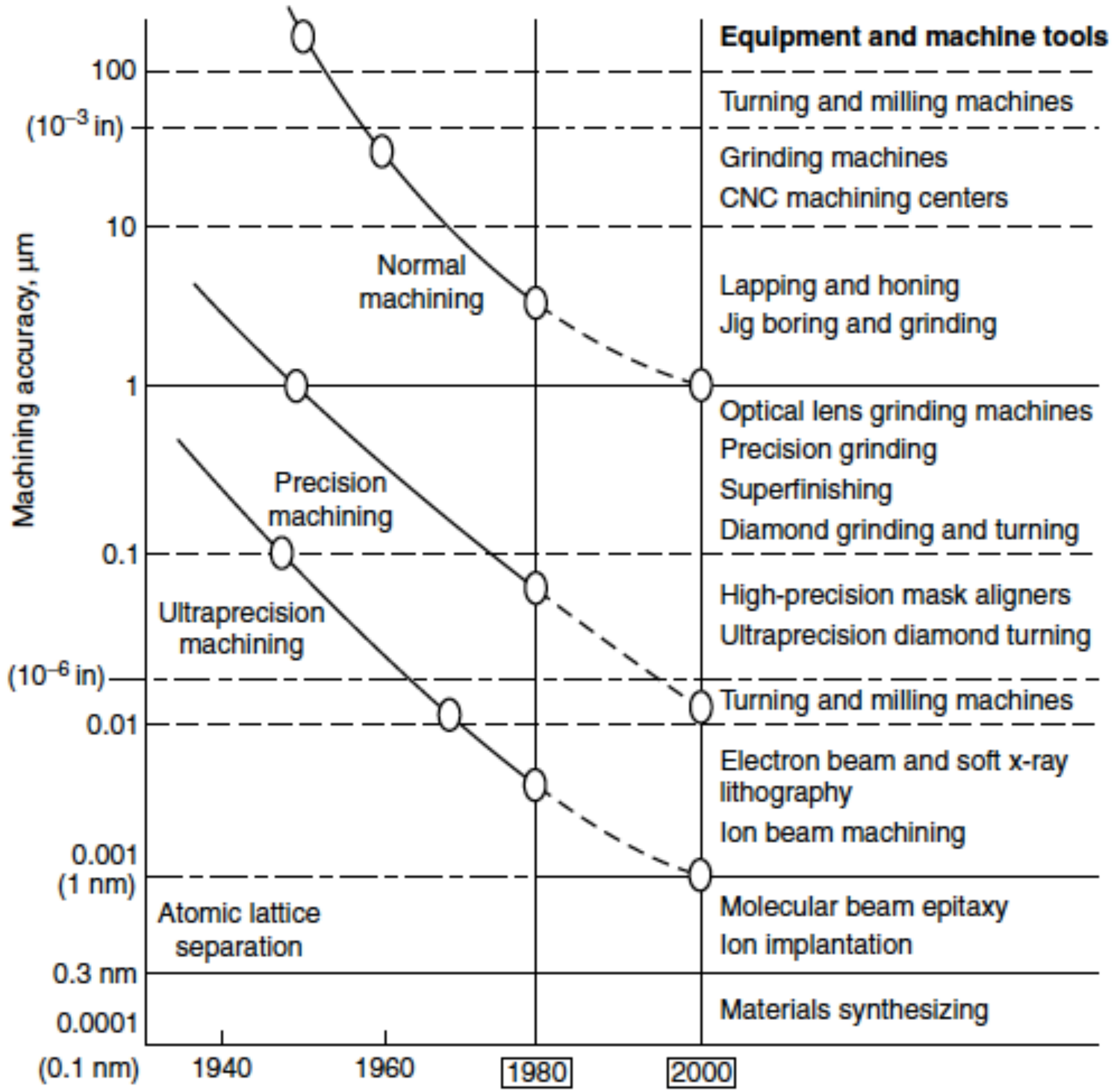
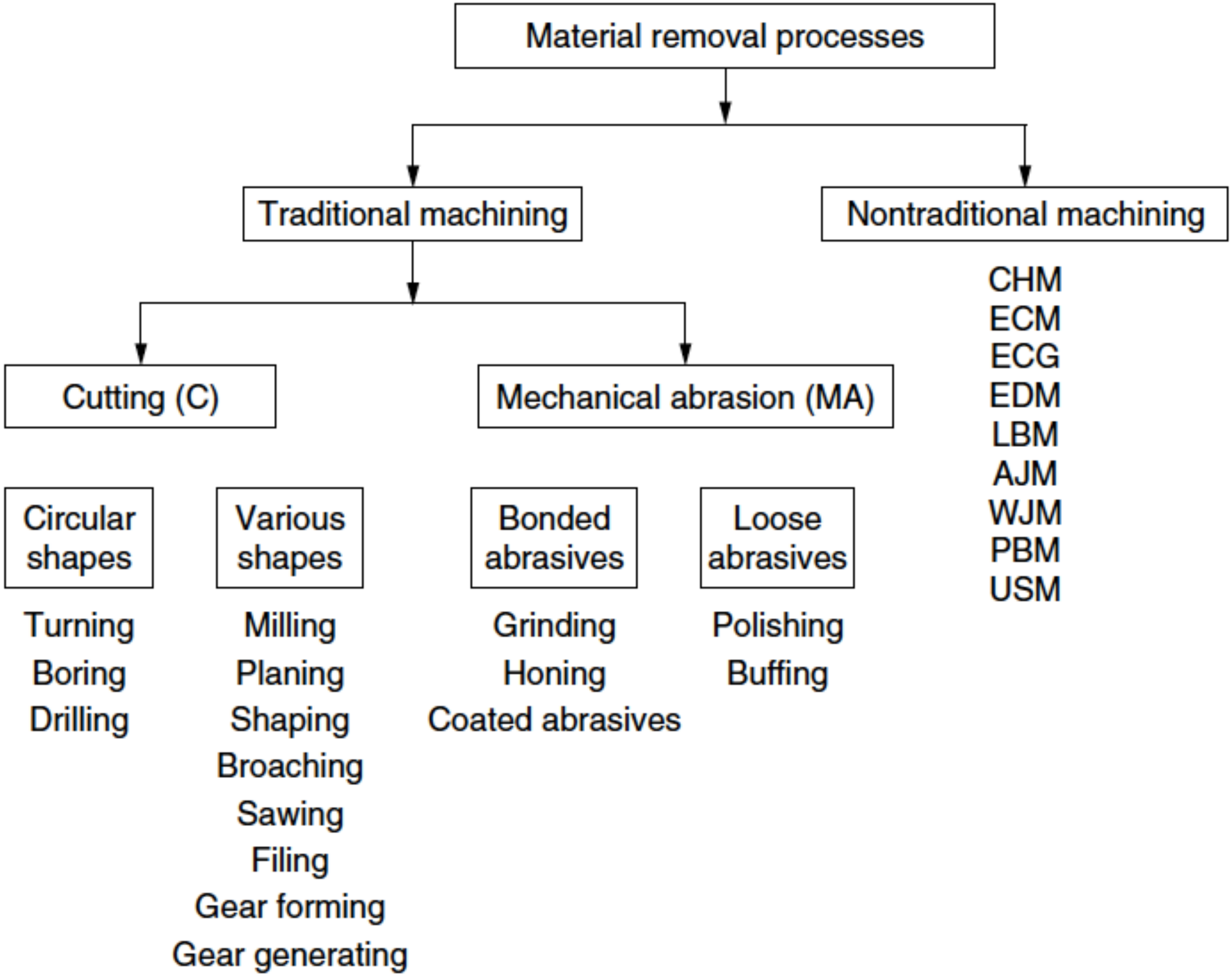
ME2300: Manufacturing Processes
Jan-May 2020

Non traditional & hybrid machining processes

Introduction




Material removal processes
Traditional machining
Nontraditional machining
CHM
ECM
ECG
EDM
LBM
AJM
WJM
PBM
USM
Cutting (C)
Mechanical abrasion (MA)
Circular shapes
Turning
Boring
Drilling
Various shapes
Milling
Planing
Shaping
Broaching
Sawing
Filing
Gear forming
Gear generating
Bonded abrasives
Grinding
Honing
Coated abrasives
Loose abrasives
Polishing
Buffing

Introduction

Manufacturing processes can be broadly divided into two groups:

a) primary manufacturing processes : Provide basic shape and size
b) secondary manufacturing processes : Provide final shape and size with tighter control on dimension, surface characteristics

Material removal processes once again can be divided into two groups

1. Conventional Machining Processes
2. Non-Traditional machining Processes or non-conventional machining processes

Conventional Machining Processes mostly remove material in the form of chips by applying forces on the work material with a wedge shaped cutting tool that is harder than the work material under machining condition

Introduction

The major characteristics of conventional machining are:

- Generally macroscopic chip formation by shear deformation

- Material removal takes place due to application of cutting forces – energy domain can be classified as mechanical

- Cutting tool is harder than work piece at room temperature as well as under machining conditions

Introduction

Non-conventional machining processes is defined as 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 tools as it needs to be used for traditional manufacturing processes.

The major characteristics of Non-conventional machining are:

1. Material removal may occur with chip formation or even no chip formation may take place. For example in AJM, chips are of microscopic size and in case of Electrochemical machining material removal occurs due to electrochemical dissolution at atomic level.

Introduction

The major characteristics of Non-conventional machining:

2. In NTM, there may not be a physical tool present. For example in laser jet machining, machining is carried out by laser beam. However in Electrochemical Machining there is a physical tool that is very much required for machining
3. In NTM, the tool need not be harder than the work piece material. For example, in EDM, copper is used as the tool material to machine hardened steels.
4. Mostly NTM processes do not necessarily use mechanical energy to provide material removal. They use different energy domains to provide machining. For example, in USM, AJM, WJM mechanical energy is used to machine material, whereas in ECM electrochemical dissolution constitutes material removal.

Classifications

Classification of NTM processes is carried out depending on the nature of energy used for material removal.

1. Mechanical Processes
- Abrasive Jet Machining (AJM)
- Ultrasonic Machining (USM)
- Water Jet Machining (WJM)
- Abrasive Water Jet Machining (AWJM)

2. Electrochemical Processes
- Electrochemical Machining (ECM)
- Electro Chemical Grinding (ECG)
- Electro Jet Drilling (EJD)

3. Electro-Thermal Processes
- Electro-discharge machining (EDM)
- Laser Jet Machining (LJM)
- Electron Beam Machining (EBM)

4. Chemical Processes
- Chemical Milling (CHM)
- Photochemical Milling (PCM)

Why non traditional machining?

- 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 Non-traditional 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

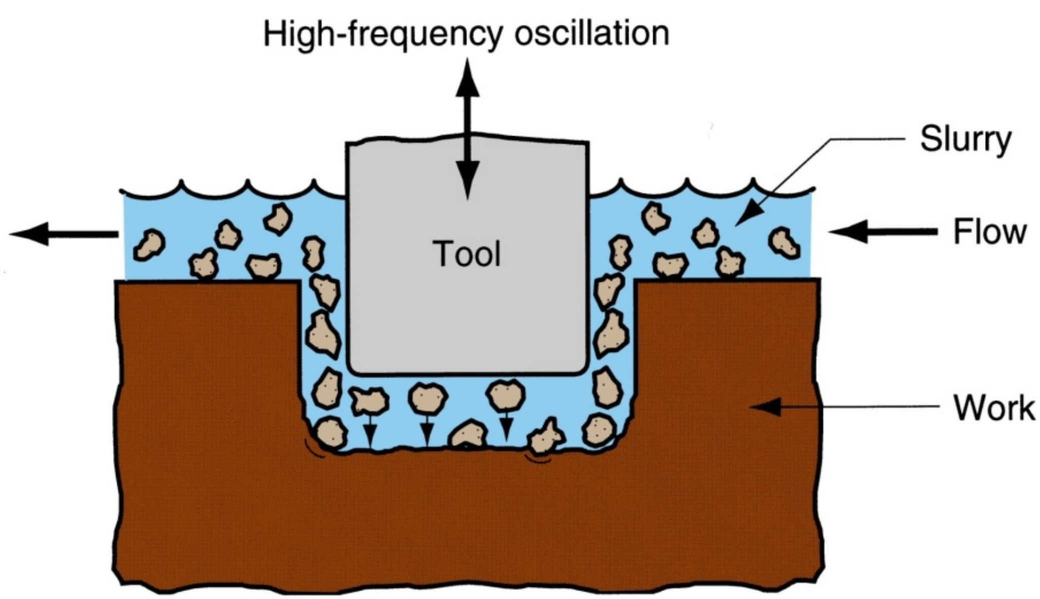
Mechanical energy processes

- Ultrasonic machining (USM)
- Water jet cutting (WJM)
- Abrasive water jet cutting (AWJM)
- Abrasive jet machining (AJM)

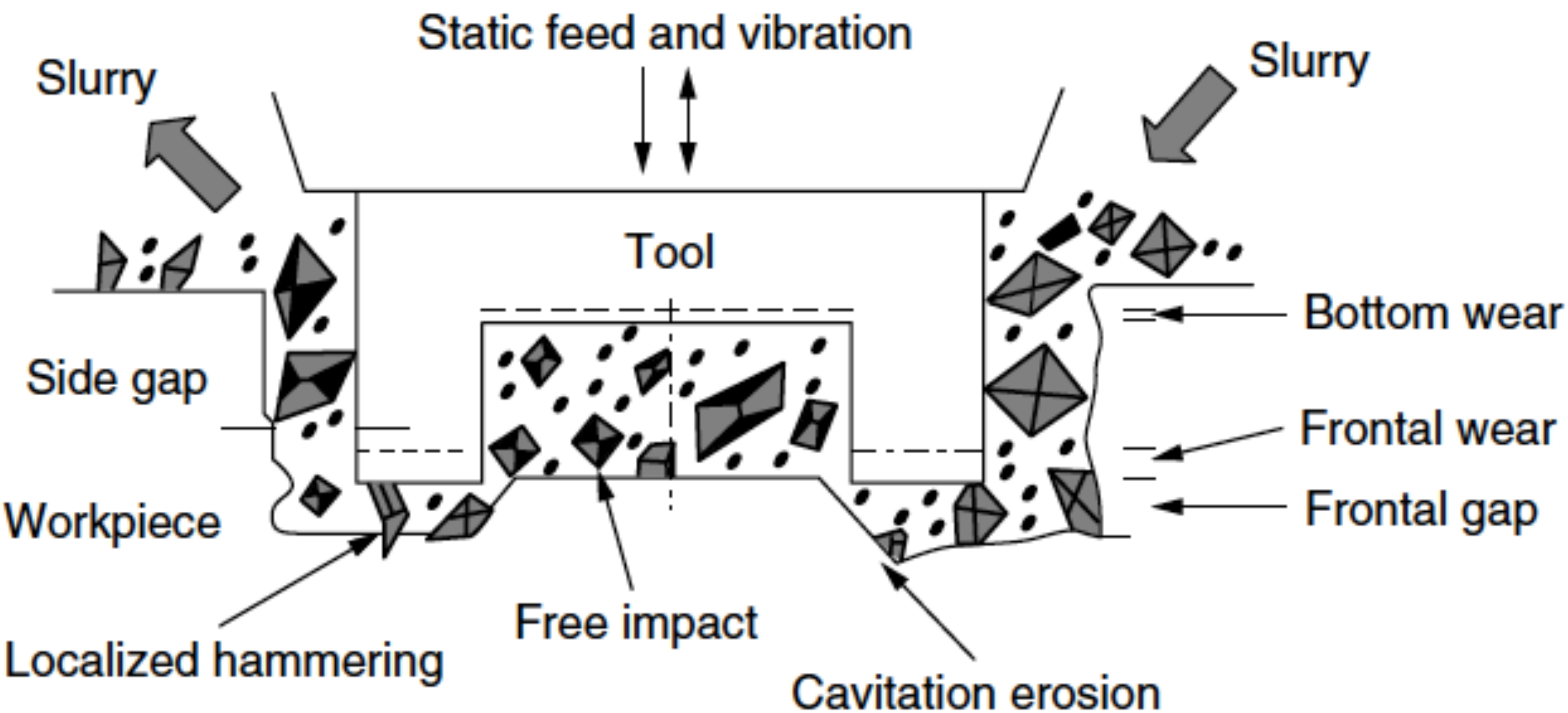
Ultrasonic Machining (USM)

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



Ultrasonic Machining (USM)



Material removal mechanisms in USM

Ultrasonic Machining (USM)

- Mechanical abrasion by localized direct hammering of the abrasive grains stuck between the vibrating tool and adjacent work surface.

- The microchipping by free impacts of particles that fly across the machining gap and strike the workpiece at random locations.

- The work surface erosion by cavitation in the slurry stream.

USM

- Applications

– USM is best suited for hard, brittle materials, such as ceramics, carbides, glass, precious stones, and hardened steels.

- Capability

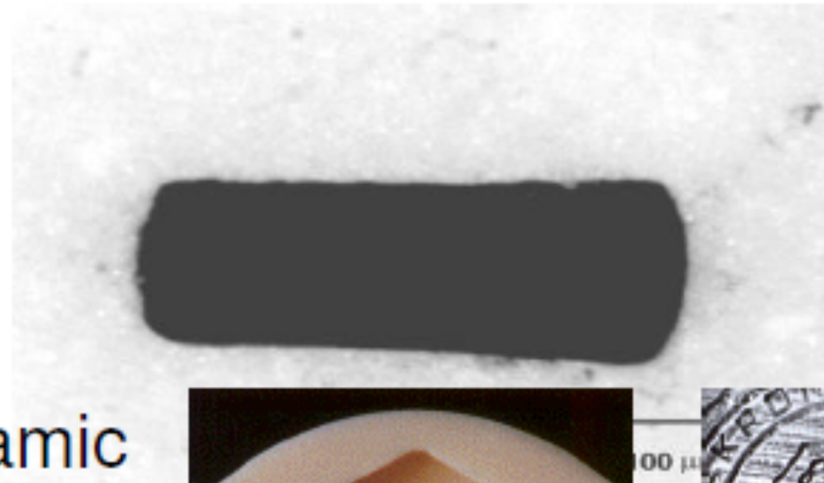
– With fine abrasives, tolerance of 0.0125 mm or better can be held. Ra varies between 0.2 – 1.6 µm.

- Pros & Cons:

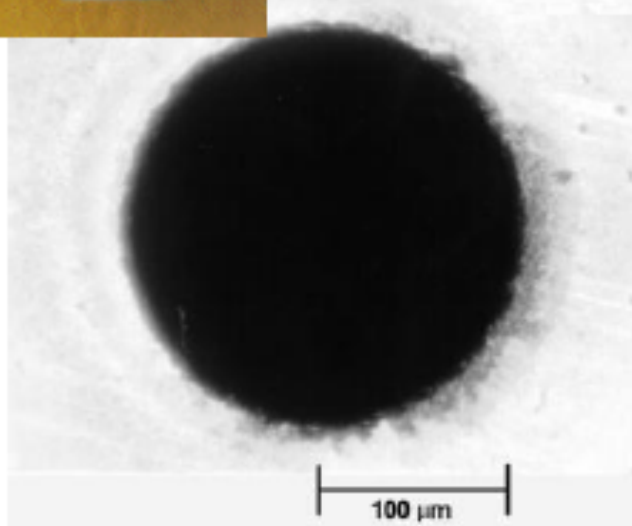
– *Pros: precise machining of brittle materials; makes tiny holes (0.3* mm); does not produce electric, thermal, chemical damage because it removes material mechanically.

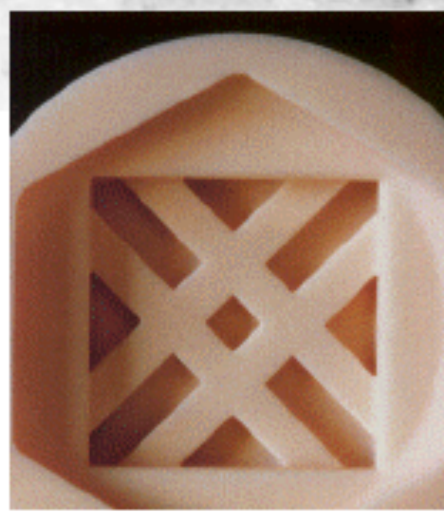
– *Cons: low material removal rate (typically 0.8 cm*^{3}*/min); tool wears* rapidly; machining area and depth are limited.

USM Parts



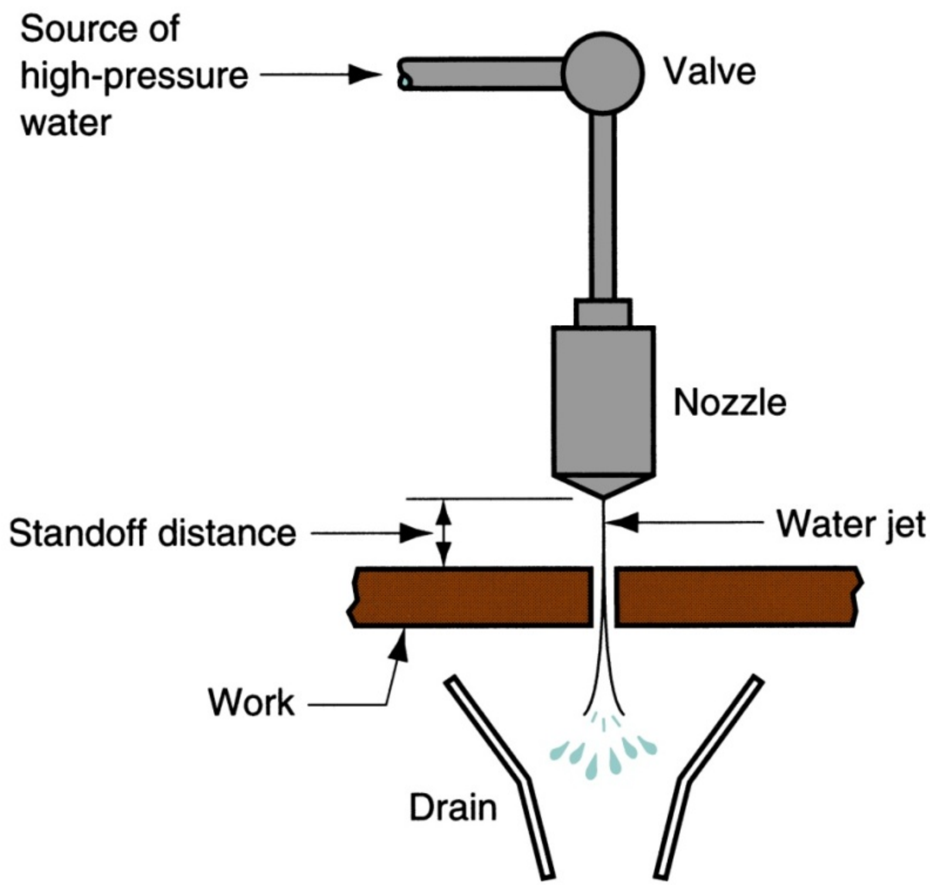
Ceramic



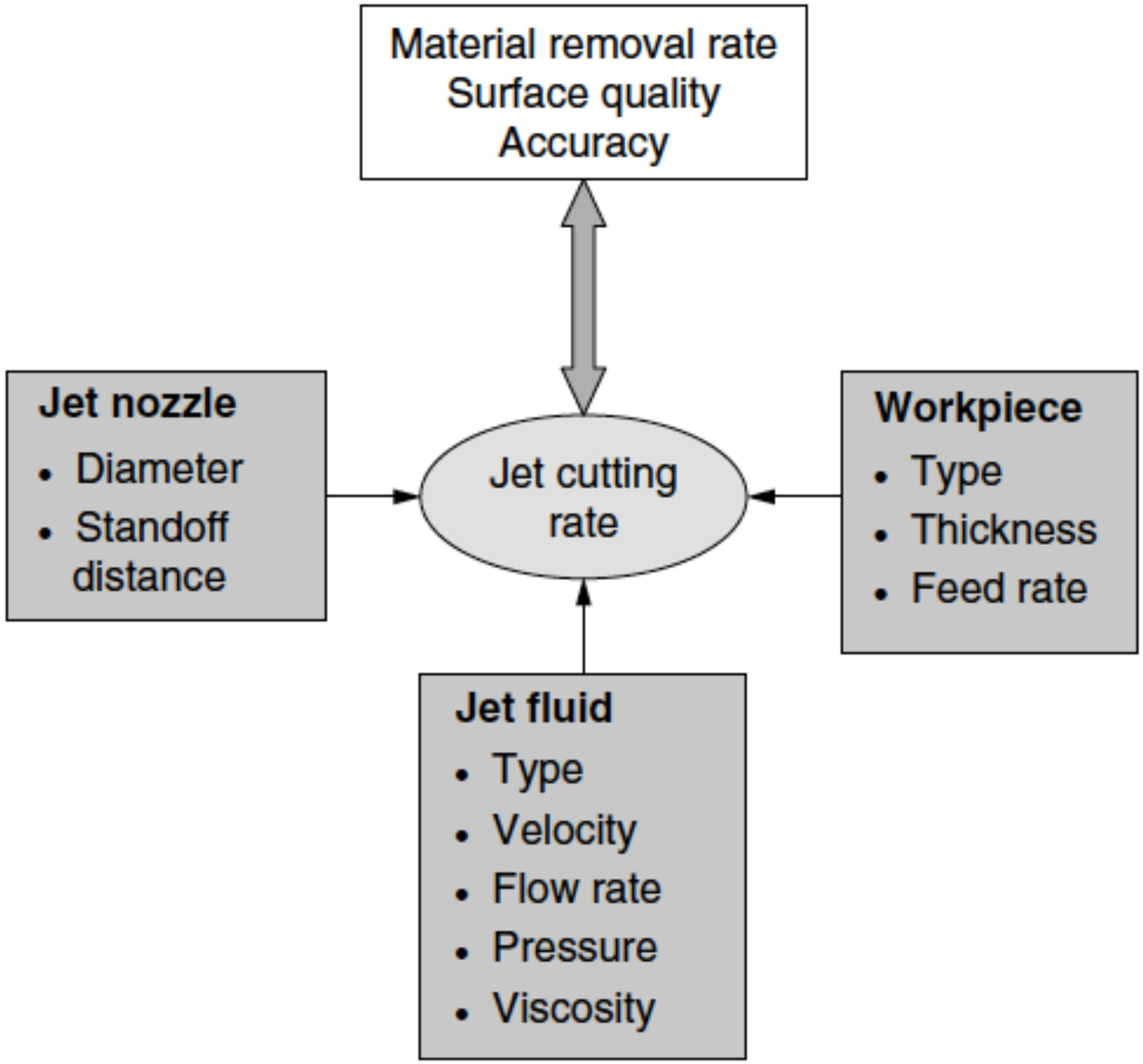


Water Jet Machining (WJM)

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



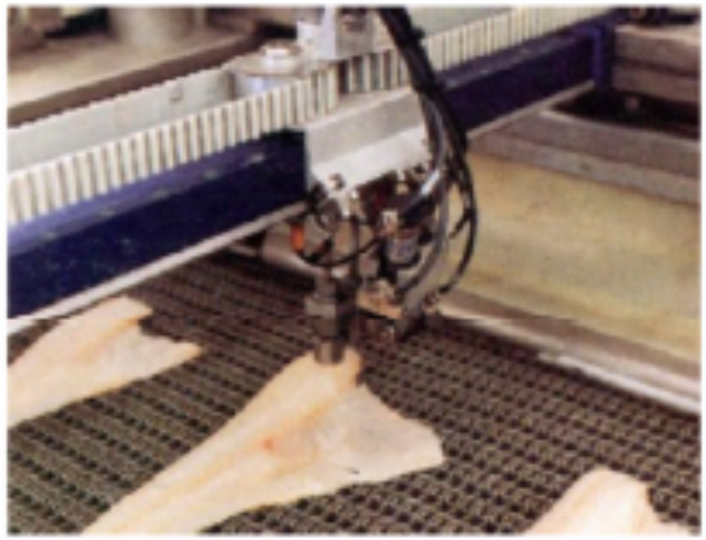
Water Jet Machining (WJM)



WJM 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

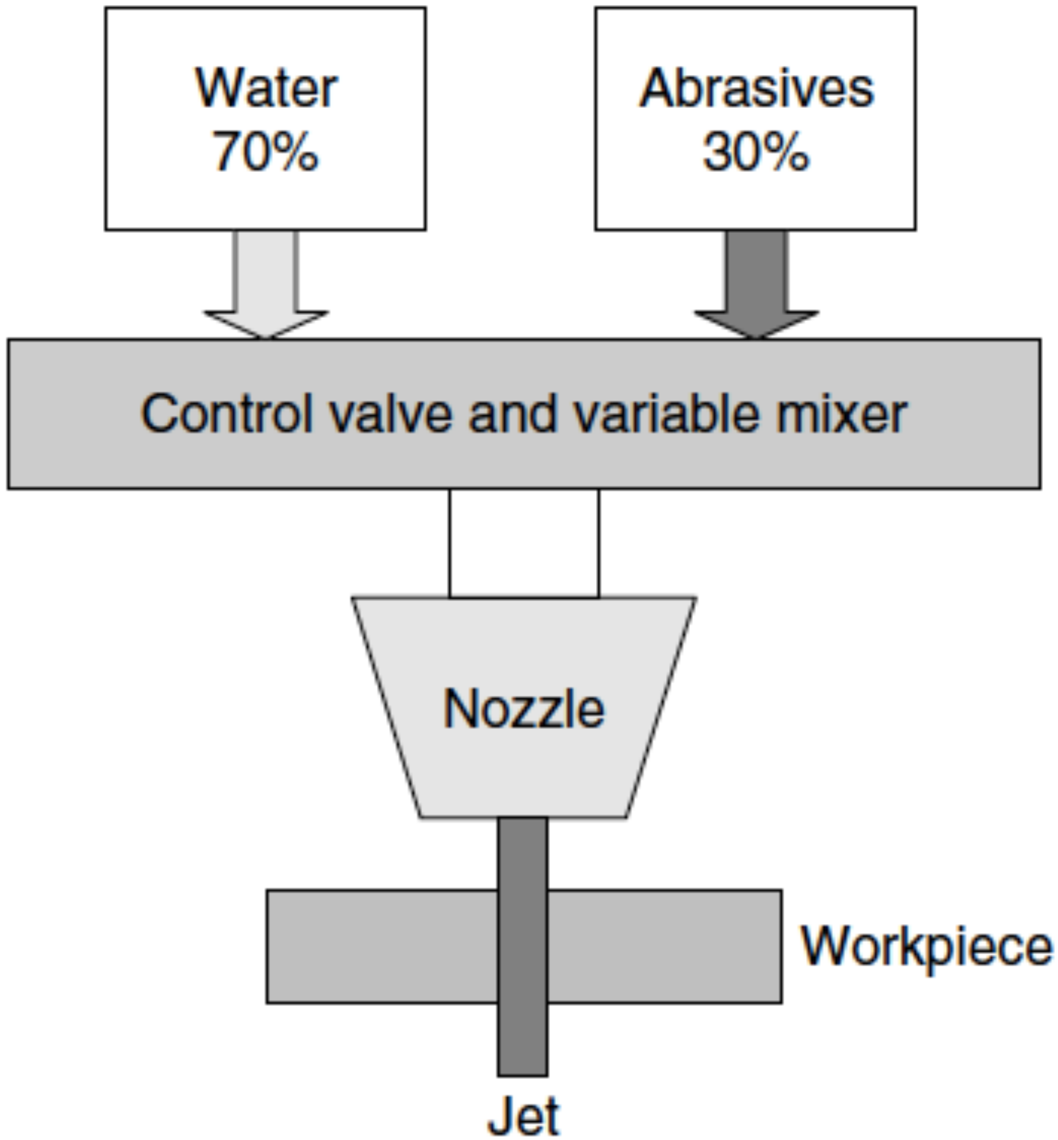
WJM Parts



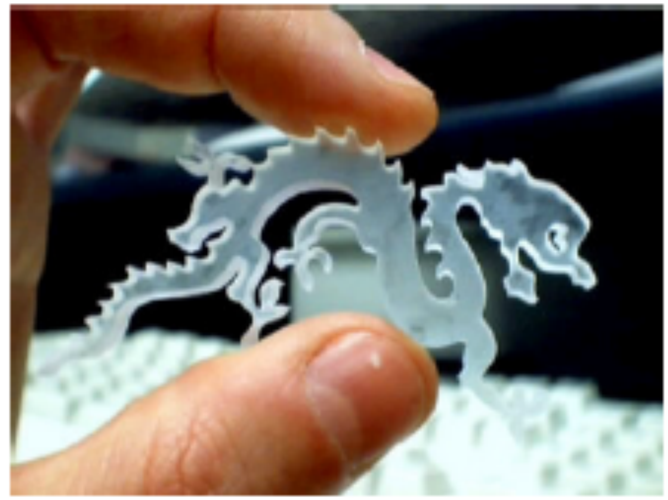
Abrasive Water Jet Machining (AWJM)

- When WJM 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

Abrasive Water Jet Machining (AWJM)



AWJM Parts



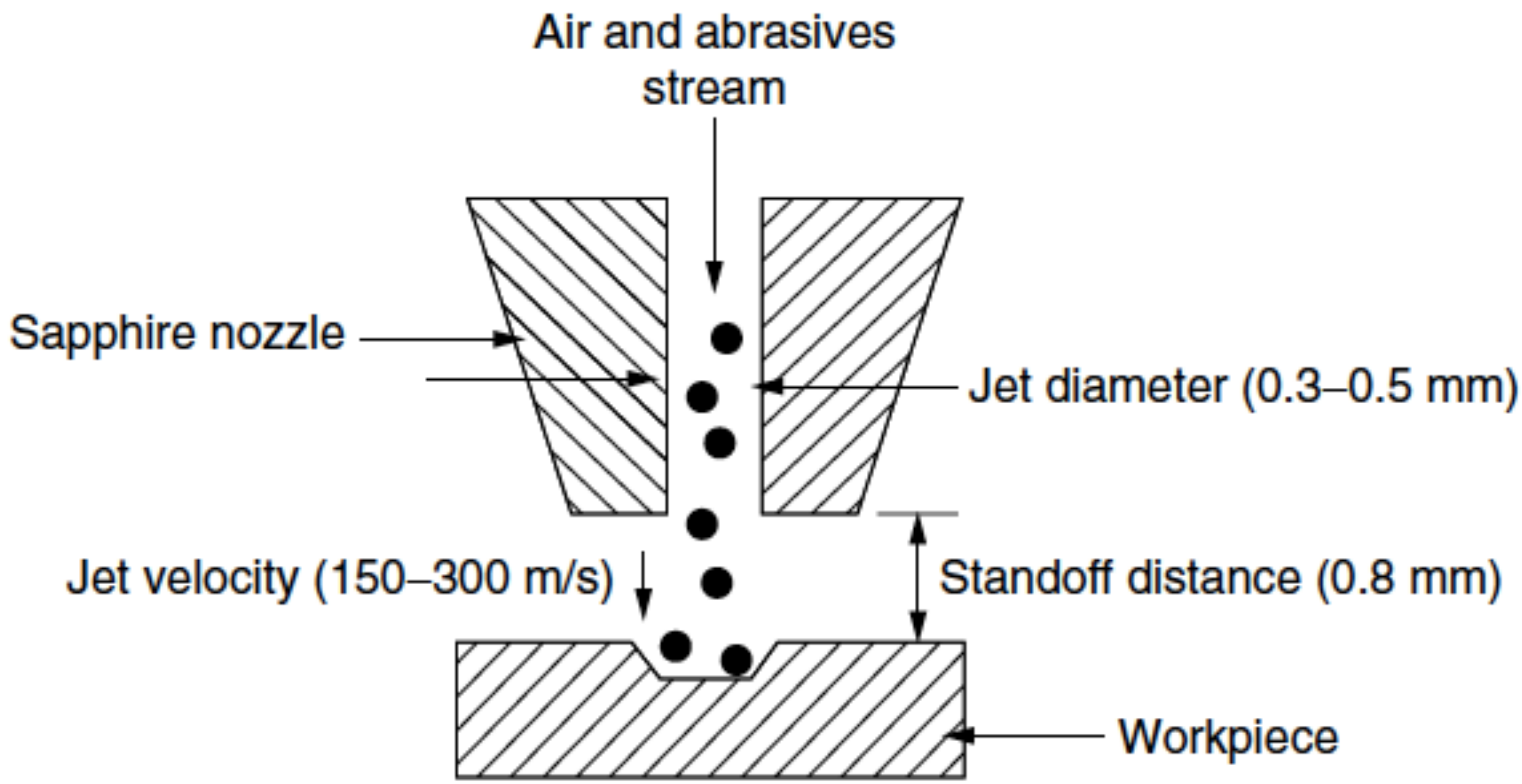
Bullet Proof Glass Part

Steel rack (75 mm thick)

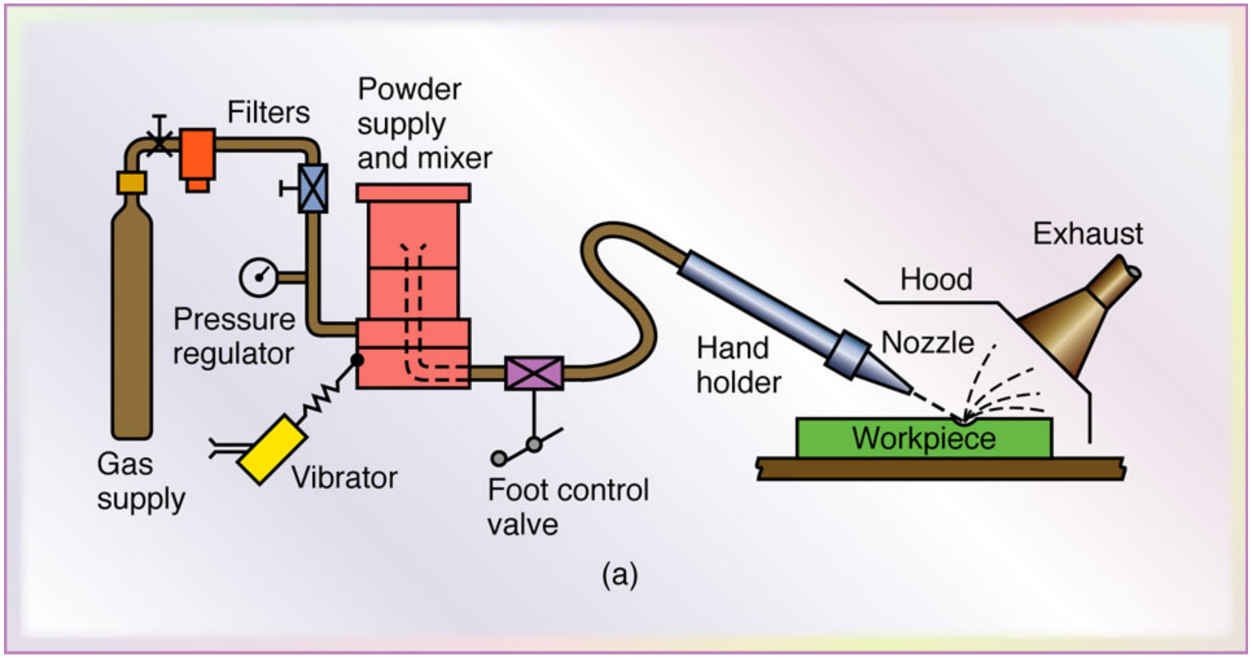
Ceramic Part

Abrasive Jet Machining (AJM)

- High velocity stream of gas containing small abrasive particles



Abrasive Jet Machining (AJM)



A high-velocity jet of dry air, nitrogen, or carbon dioxide containing abrasive particles is aimed at the workpiece surface under controlled conditions.

The gas supply pressure is on the order of 850 kPa (125 psi) and the jet velocity can be as high as 300 m/s and is controlled by a valve.

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, ceramics)

AJM process capability

- Material removal
  - Typical cutting speeds vary between 25 -125 mm/min
- Dimensional Tolerances
  - Typical range ± 2 - ± 5 μm
- Surface Finish
  - Typical R_a values vary from 0.3 - 2.3 μm

AJM

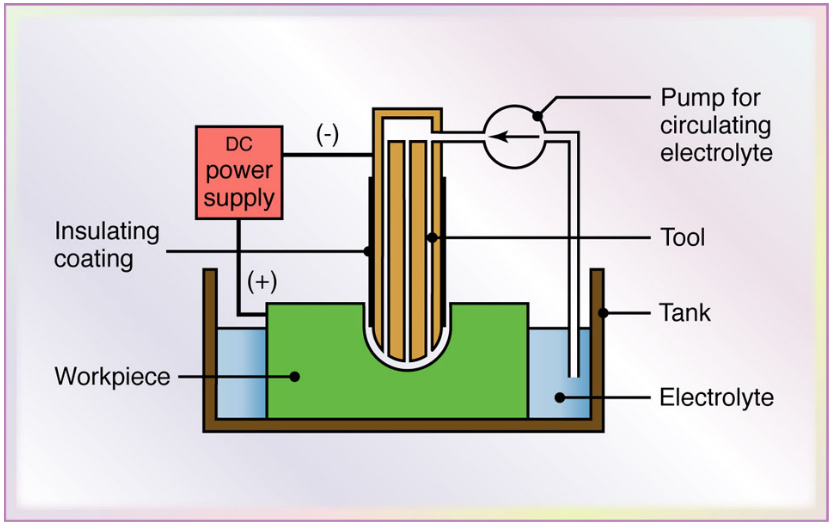
- Applications
  - Can cut traditionally hard to cut materials, e.g., composites, ceramics, glass
  - Good for materials that cannot stand high temperatures

- Limitations
  - Expensive process
  - Flaring can become large
  - Not suitable for mass production because of high maintenance requirements

II. Electrochemical Machining Processes

- Electrochemical machining (ECM) is a modern machining process that relies on the removal of workpiece atoms by electrochemical dissolution (ECD) in accordance with the principles of Faraday (1833).
- Reverse of electroplating
- Work material must be a conductor
- Processes:
  - Electrochemical machining (ECM)
  - Electrochemical grinding (ECG)

Electrochemical Machining (ECM)



- Process description:

– In ECM, a dc voltage (10-25 V) is applied across the gap between a pre-shaped cathode tool and an anode workpiece. The workpiece is dissolved by an electrochemical reaction to the shape of the tool.

– The electrolyte flows at high speed (10-60 m/s) through the gap (0.1-0.6 mm) to dissipate heat and wash away the dissolved metal.

Electrochemical Machining (ECM)

The amount of metal dissolved (removed by machining) or deposited is calculated from Faraday's laws of electrolysis, which state that

- The amount of mass dissolved (removed by machining), m , is directly proportional to the amount of electricity.
- The amount of different substances dissolved, m, by the same quantity of electricity is proportional to the substances' chemical equivalent weight e.

Electrochemical Machining (ECM)

- The material removal rate by ECM is given by:

$$MRR = C\,I\,\eta$$

where, MRR=mm^3/min, I=current in amperes,

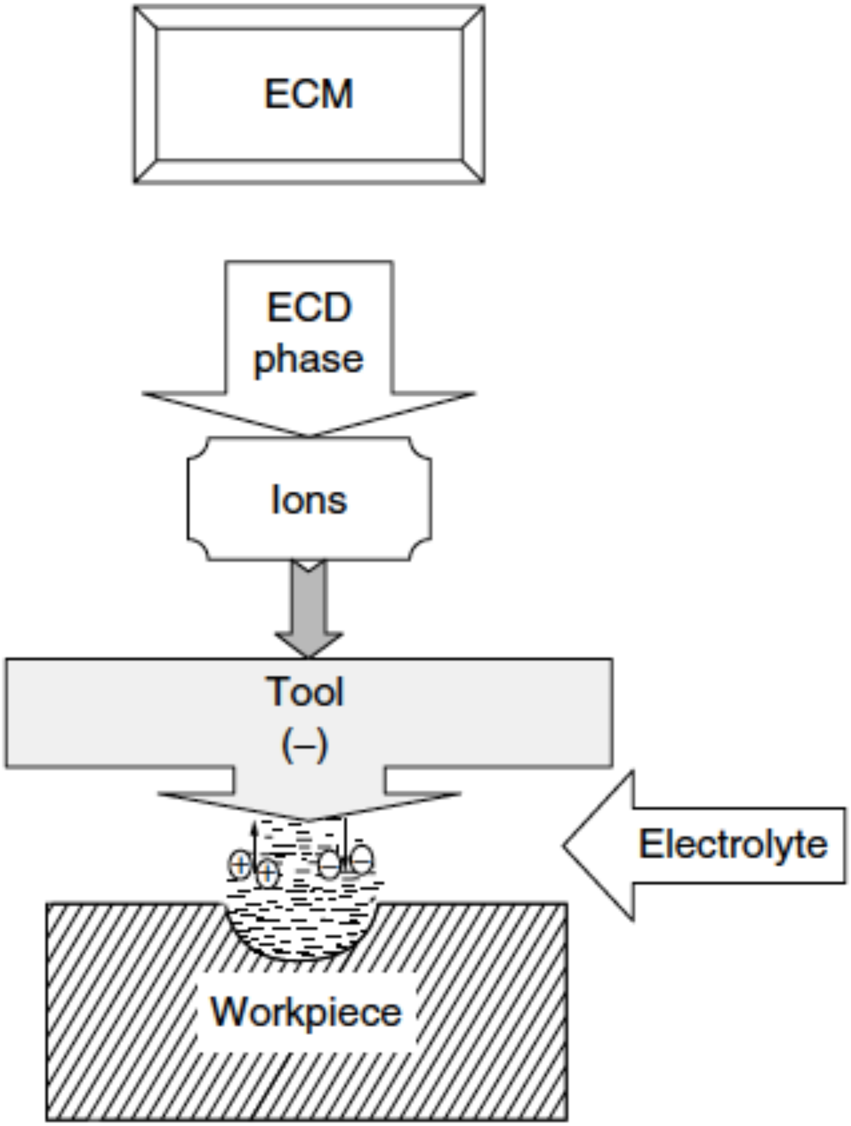
η=current efficiency, which typically ranges from 90-100%,

C is a material constant in mm^3/A·min.

Feed rate (mm/min): $f = MRR / A_0$

Assuming a cavity with uniform cross-sectional area A_0

Electrochemical Machining (ECM)

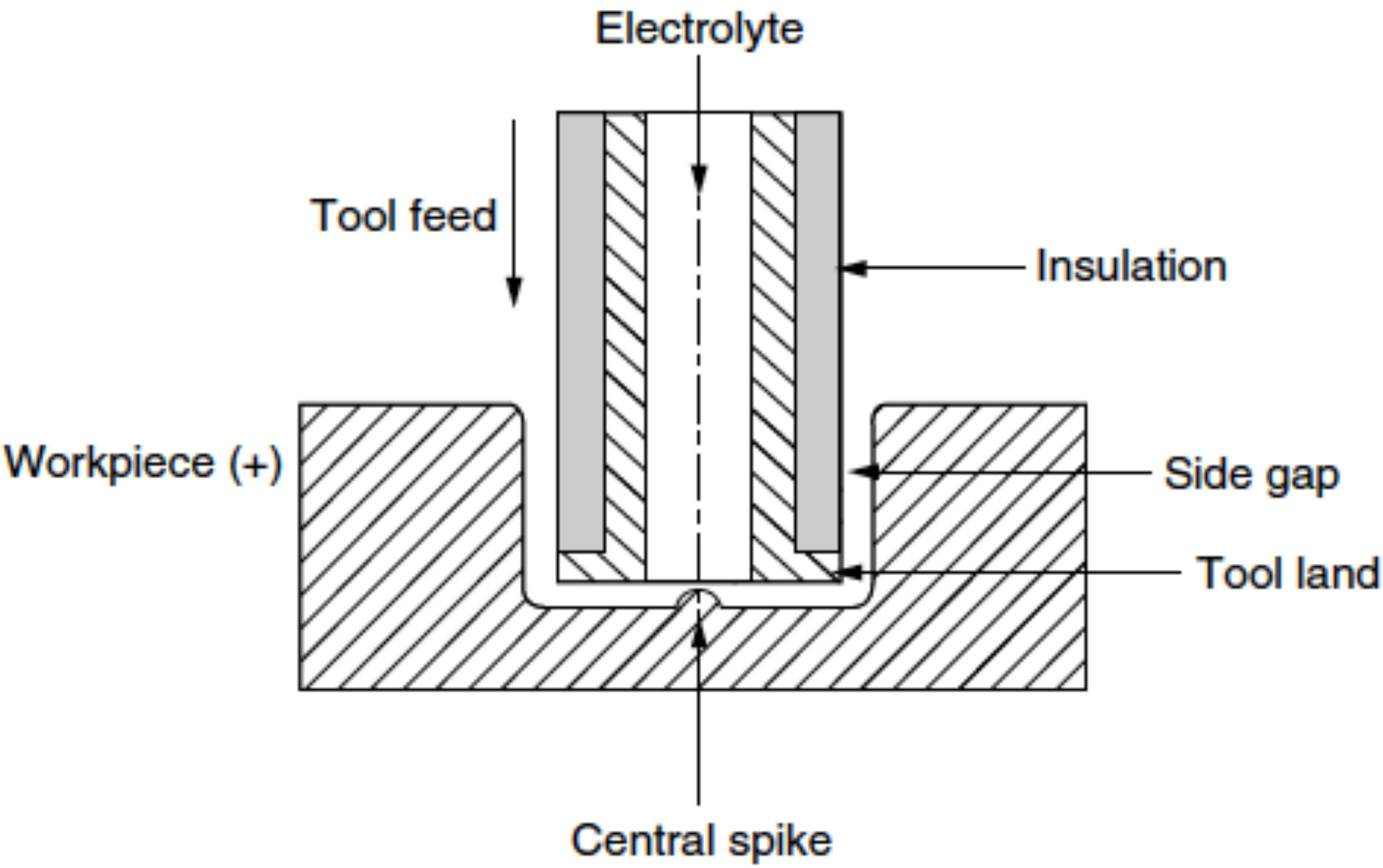


ECM process components

Electrochemical Machining (ECM)

- There is no wear in the tool because there is no contact between the tool and the workpiece.
- Machining is done at low voltages, compared to other processes, with high metal removal rates.
- Very small dimensions up to 0.05 mm can be controlled.
- Complicated profiles can be machined easily in a single operation.

Electrochemical Drilling (ECDR)



ECDR configuration

III. Thermal Energy Processes

- 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

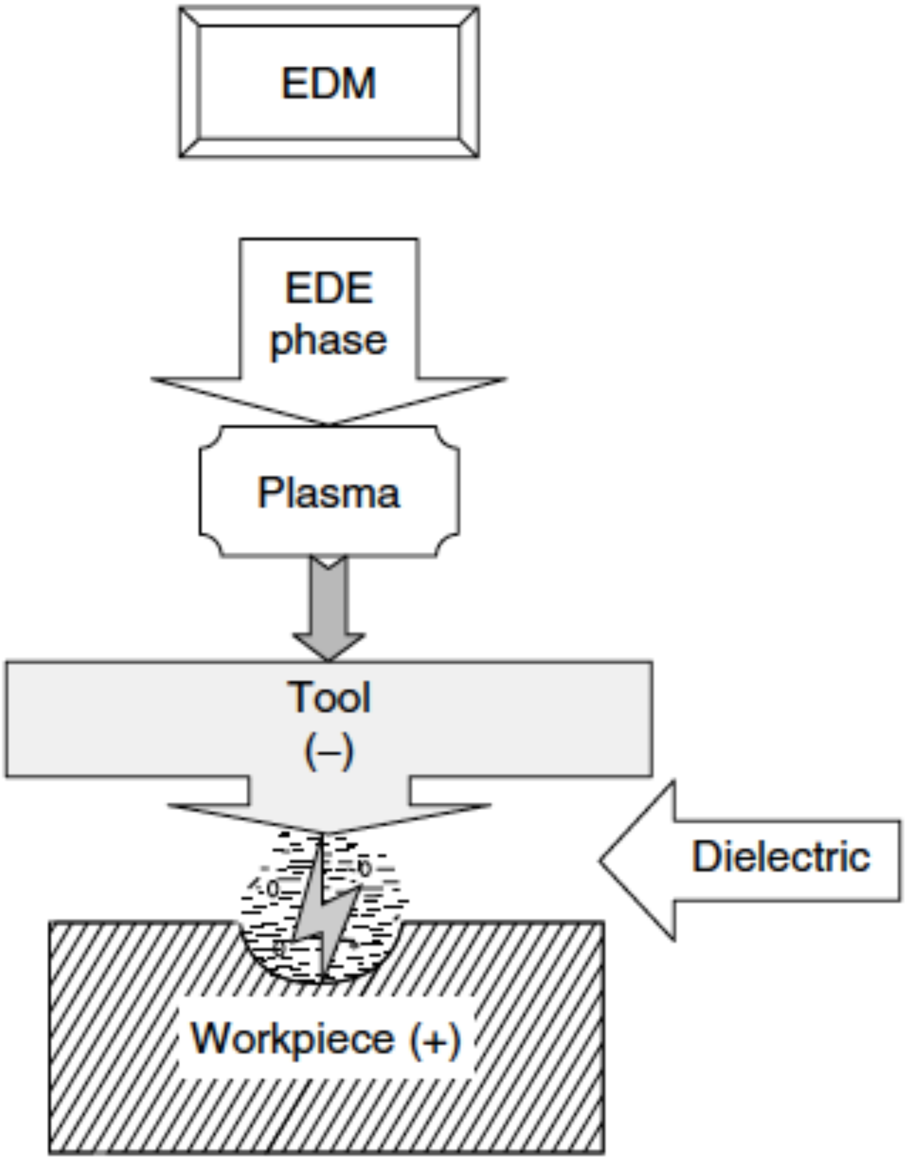
Thermal Energy Processes

- Electric discharge machining
- Electric discharge wire cutting
- Electron beam machining
- Laser beam machining
- Plasma arc machining

Electric Discharge Processes

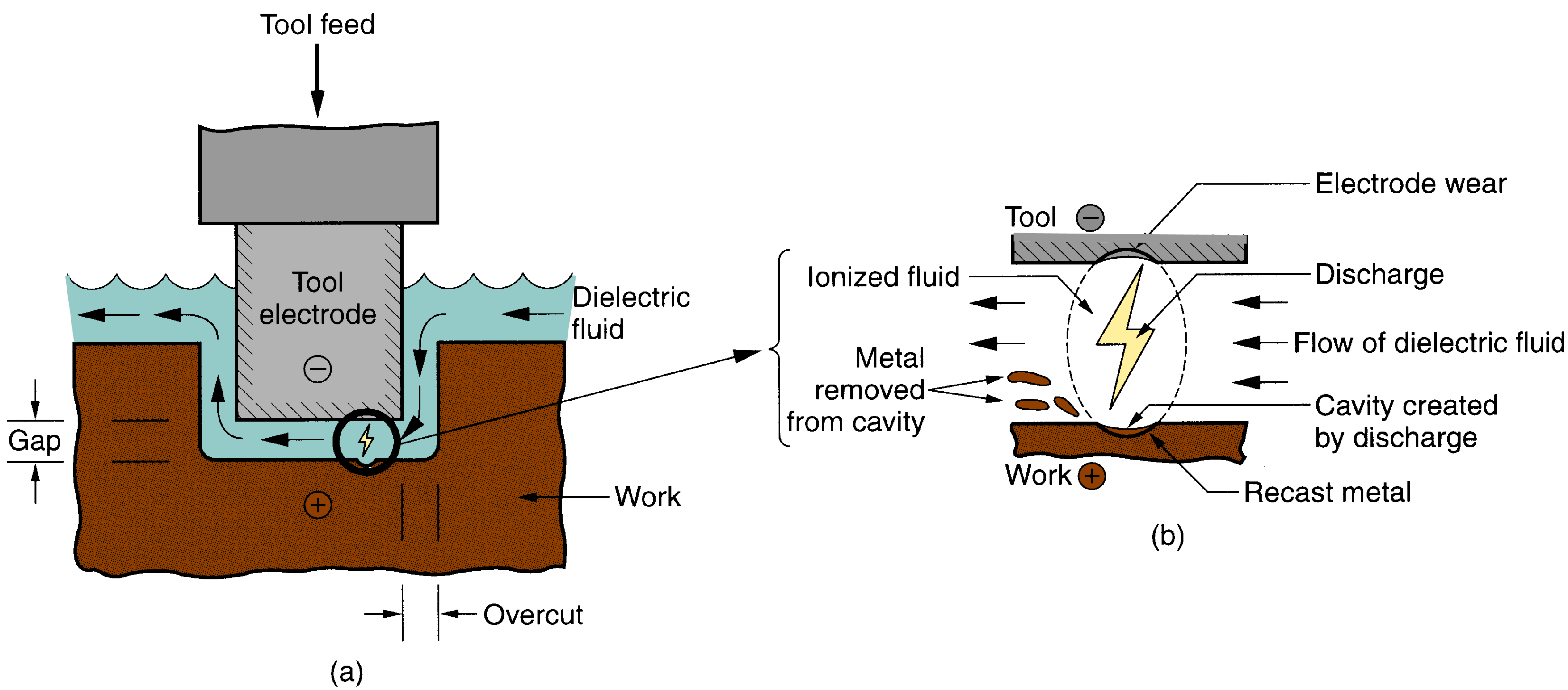
- In EDM, the removal of material is based upon the electro-discharge erosion (EDE) effect of electric sparks occurring between two electrodes that are separated by a dielectric liquid.
- Metal removal takes place as a result of the generation of extremely high temperatures generated by the high-intensity discharges that melt and evaporate the two electrodes.
- A series of voltage pulses of magnitude about 20 to 120 V and frequency on the order of 5 kHz is applied between the two electrodes, which are separated by a small gap, typically 0.01 to 0.5 mm.

Electric Discharge Processes



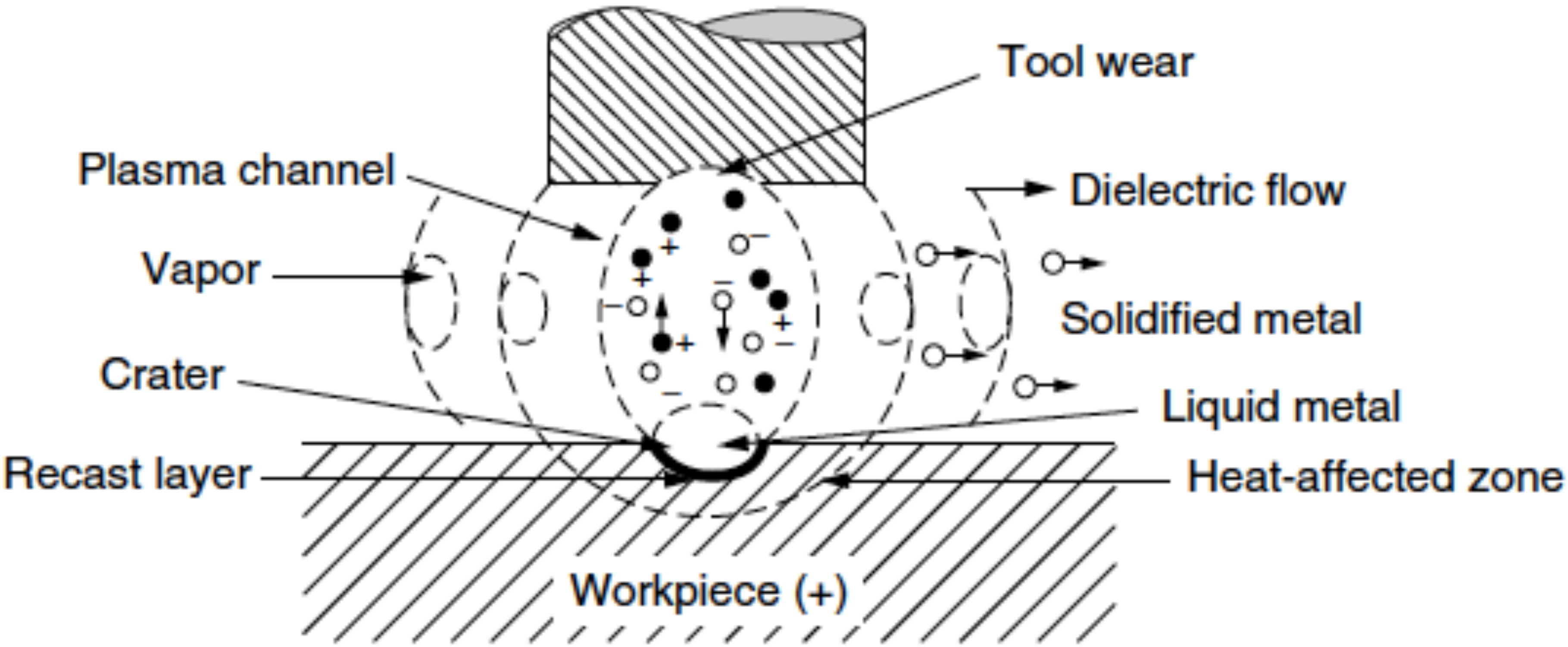
EDM components

Electric Discharge Machining (EDM)



EDM is a thermal erosion process whereby material is melted and vaporized from an electrically conducive workpiece immersed in a liquid dielectric with a series of spark discharges between the tool electrode and the workpiece created by a power supply.

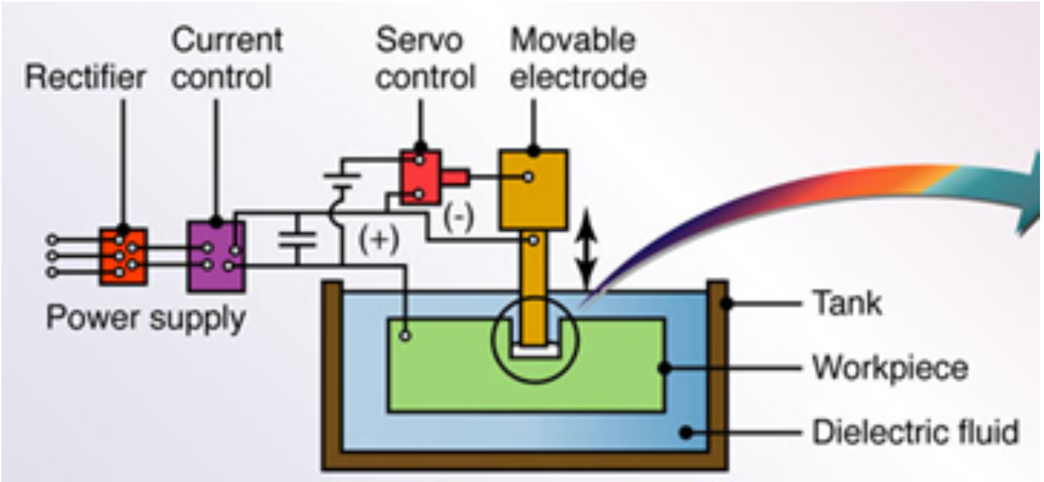
EDM machining



EDM spark description

Electric Discharge Machining (EDM)

The EDM system consists of a shaped tool or wire electrode, and the part. The part is connected to a power supply to create a potential difference between the workpiece and the tool. When the potential difference is sufficiently high, a transient spark discharges through the fluid, removing a very small amount of metal from the workpiece.



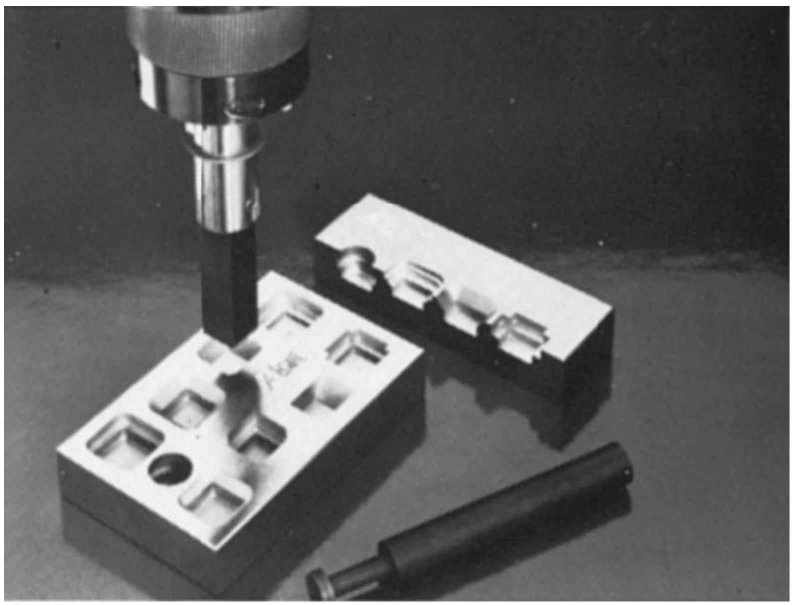
The dielectric fluid 1) acts as an insulator until the potential is sufficiently high, 2) acts as a flushing medium, and 3) provides a cooling medium.

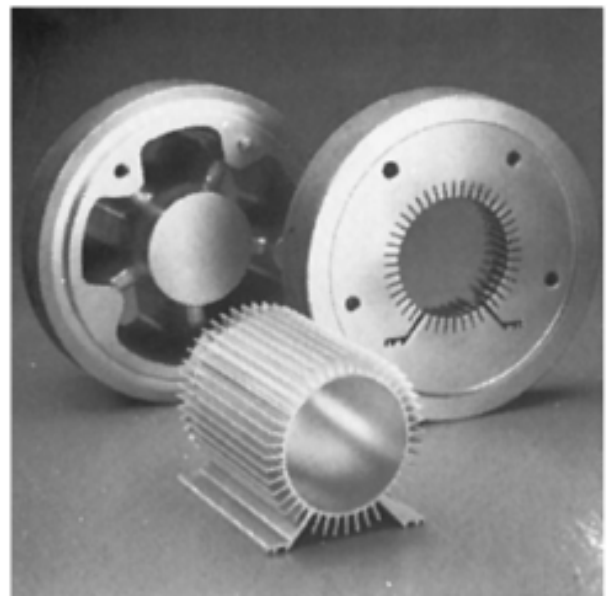
EDM process capabilities

- MRR
  - Range from 2 to 400 mm^3/min. High rates produce rough finish, having a molten and recast structure with poor surface integrity and low fatigue properties.
- Dimensional Tolerances
  - Function of the material being processed
  - Typically between $\pm$0.005 - $\pm$0.125 mm
- Surface Finish
  - Depends on current density and material being machined
  - R_a varies from 0.05 – 12.5 μm
  - New techniques use an oscillating electrode, providing very fine surface finishes.

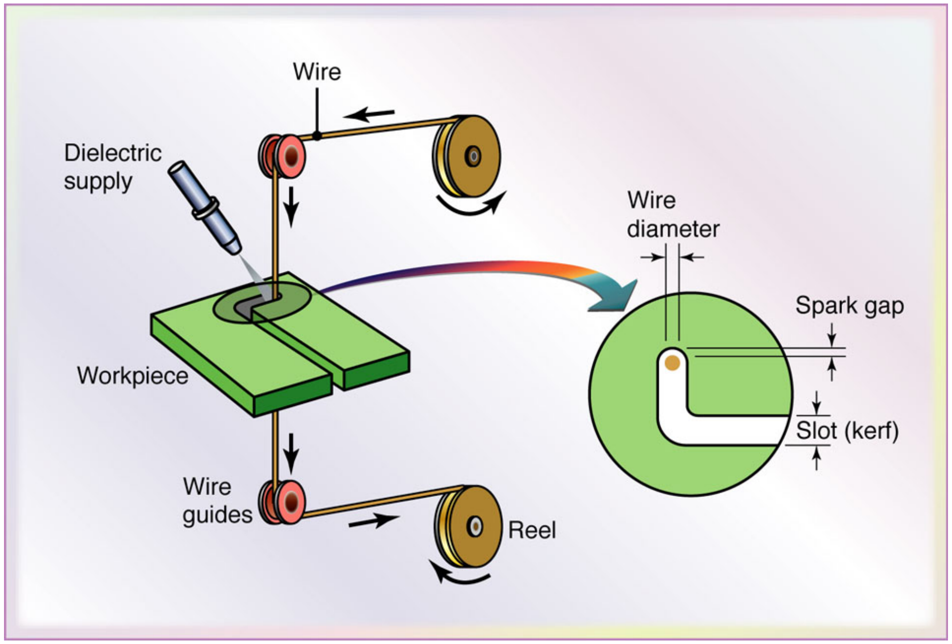
EDM Applications

- Tooling for many mechanical processes: molds for plastic injection molding, extrusion dies, wire drawing dies, forging and heading dies, and sheet metal stamping dies





Wire EDM



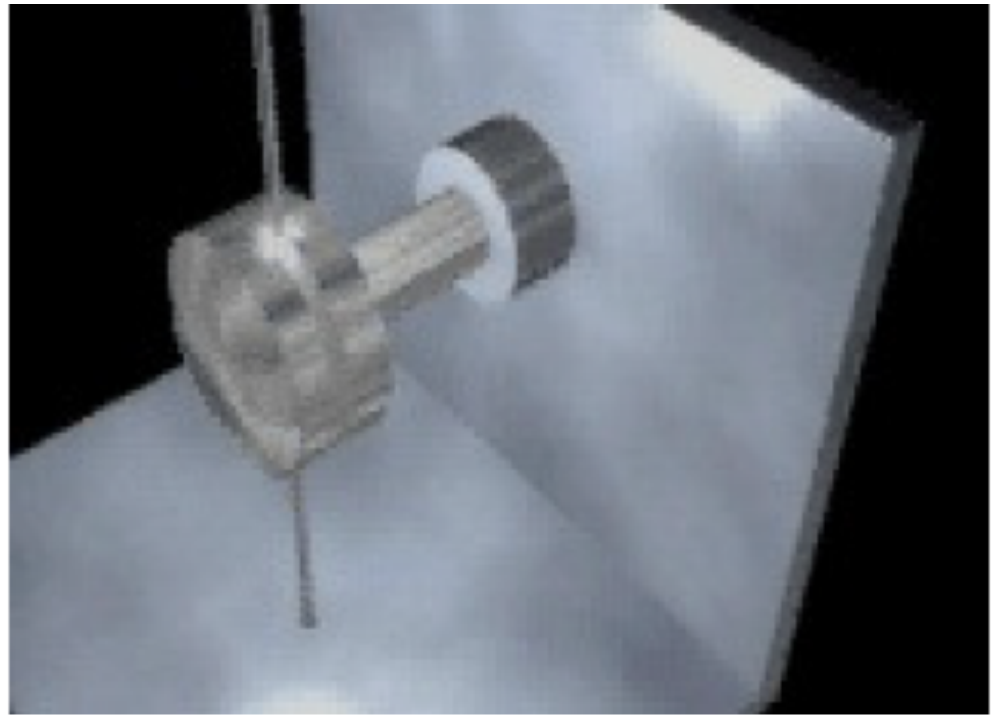
A wire travels along a prescribed path, cutting the workpiece, with the discharge sparks acting like cutting teeth.

Wire EDM

MRR in Wire EDM

$$MRR = V_f\, h\, b$$

$$where,\ b = d_w + 2s$$



MRR = mm^3/min

V_f = feed rate of wire into the workpiece in mm/min

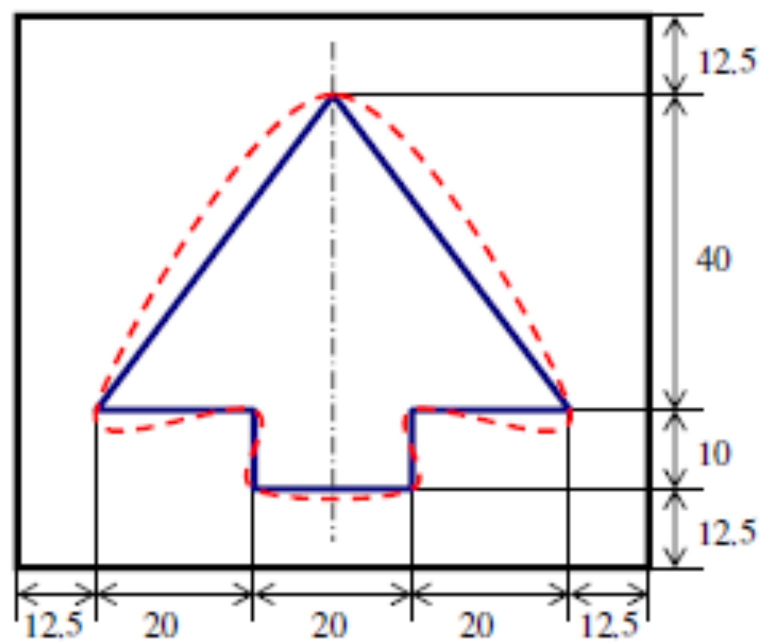
h = workpiece thickness

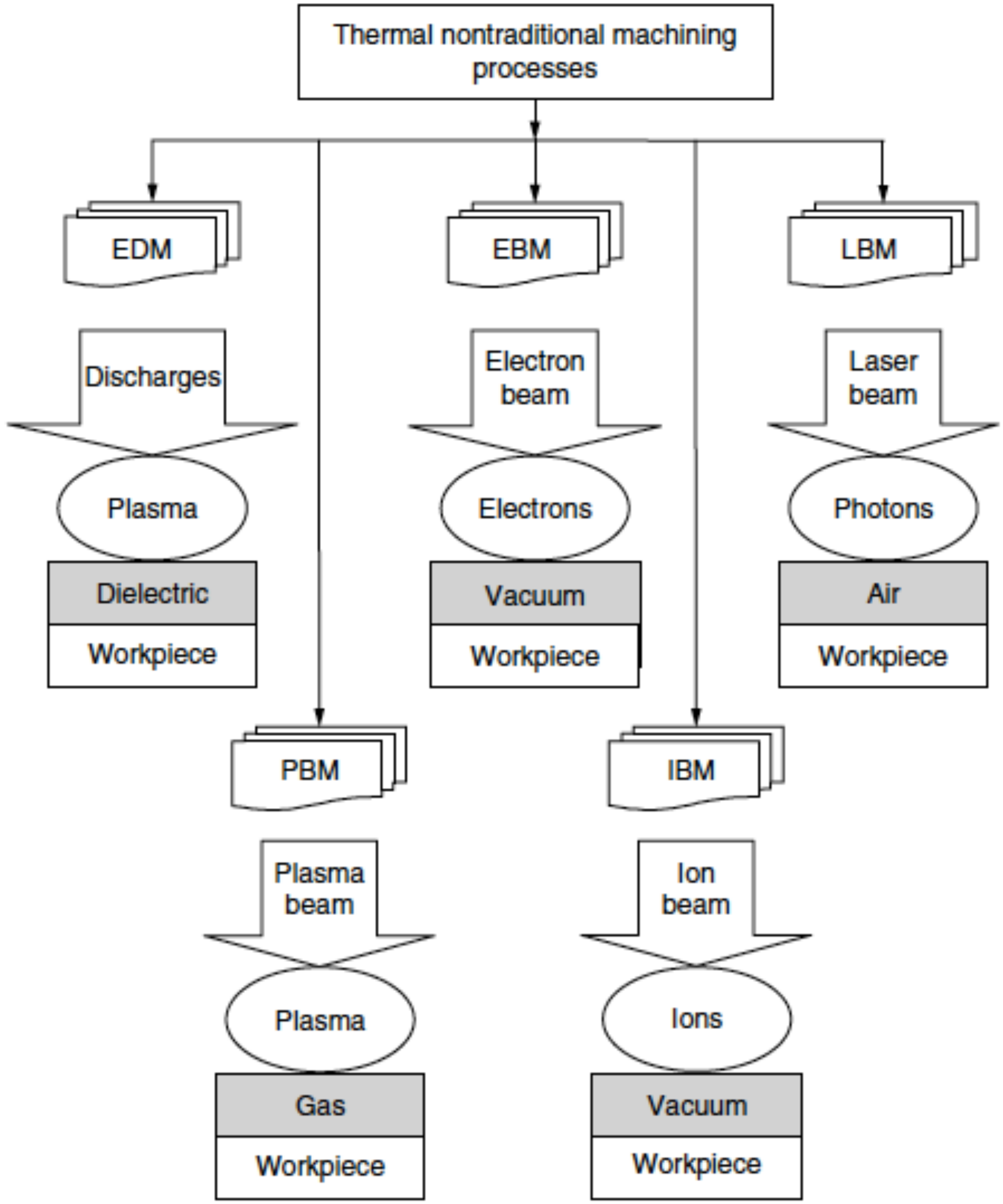
d_w = wire diameter in mm
s = gap between wire and workpiece in mm

Example

You have to machine the following part from a 85mmx75mmx20mm steel block. You have to choose between EDM and Conventional machining. Your objective is to minimize the cutting power required, which process will you choose?

Assumptions:
– EDM process:
• Wire diameter: d_w=0.2 mm
• Gap: s=0.1 mm
– Conventional machining:
• Negative of the part has to be removed



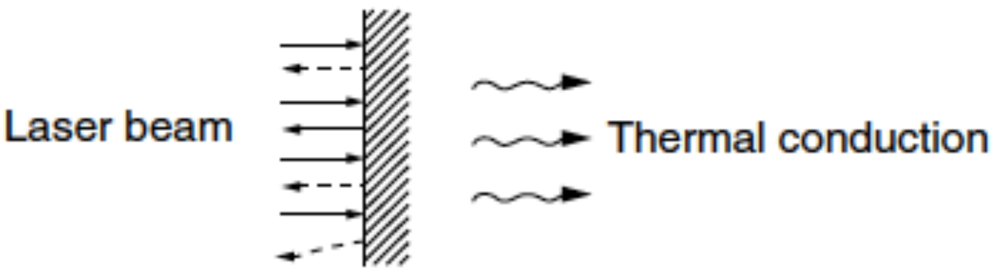


Thermal nontraditional machining processes
EDM
Discharges
Plasma
Dielectric
Workpiece
EBM
Electron beam
Electrons
Vacuum
Workpiece
LBM
Laser beam
Photons
Air
Workpiece
PBM
Plasma beam
Plasma
Gas
Workpiece
IBM
Ion beam
Ions
Vacuum
Workpiece

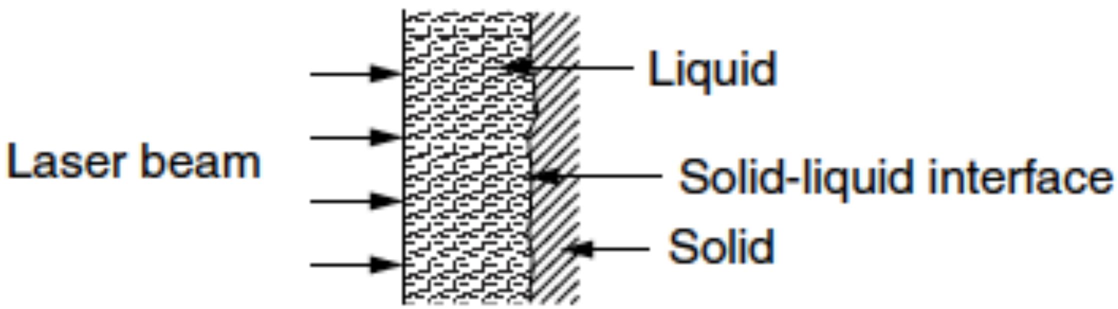
Laser Beam Machining (LBM)

- Modern machining methods are established to fabricate difficult-to-machine materials such as high-strength thermal-resistant alloys; various kinds of carbides, fiber-reinforced composite materials, Stellites, and ceramics.
- Laser beam machining (LBM) offers a good solution that is indeed more associated with material properties such as thermal conductivity and specific heat as well as melting and boiling temperatures.
- A highly collimated, monochromatic, and coherent light beam is generated and focused to a small spot. High power densities (10^6 W/mm^2) are then obtained.

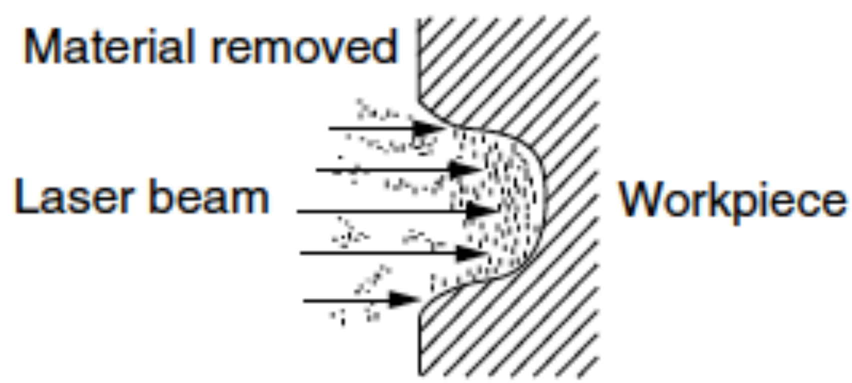
Laser Beam Machining (LBM)



(a) Absorption and heating



(b) Melting



(c) Vaporization

Physical processes occurring during LBM

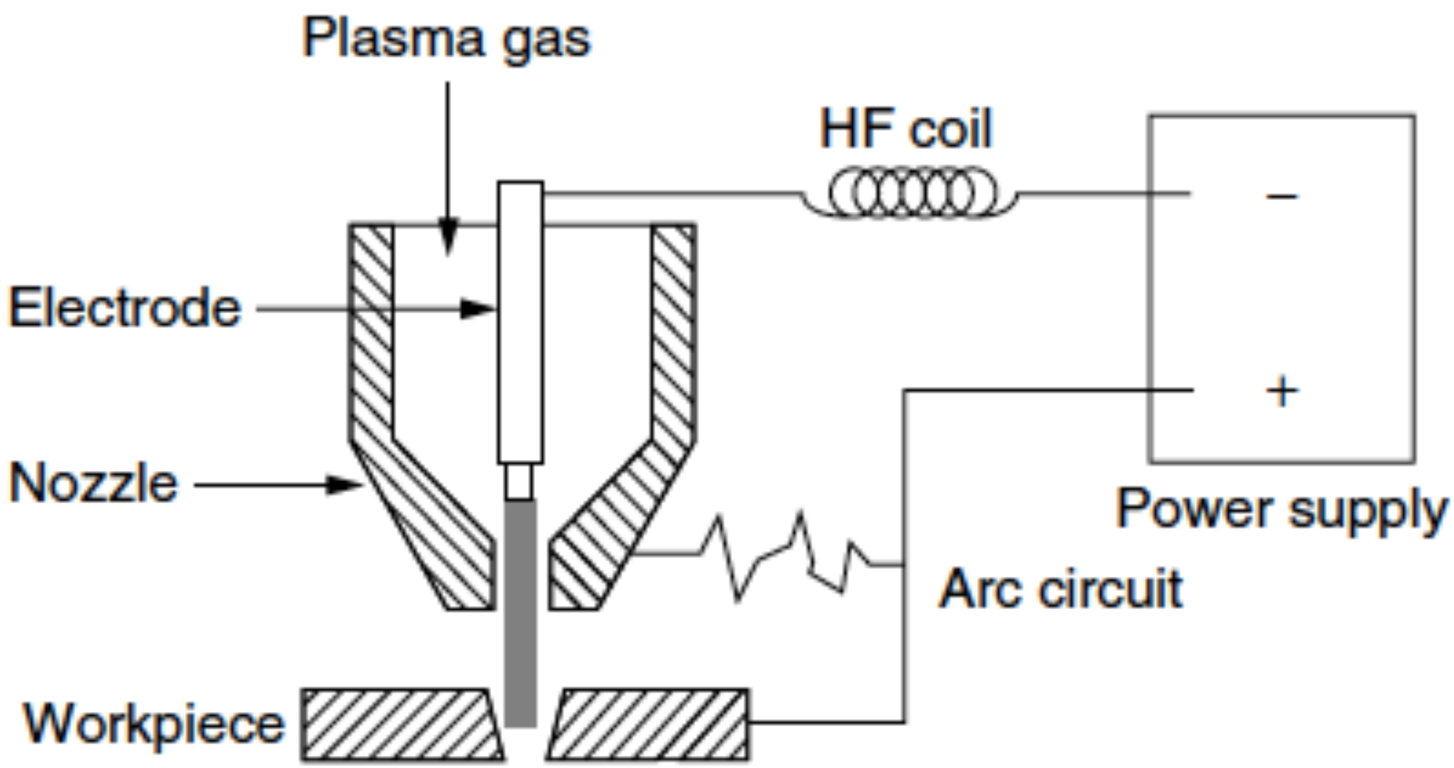
Plasma Beam Machining (PBM)

When the temperature of a gas is raised to about 2000°C, the gas molecules become dissociated into separate atoms. At higher temperatures, 30,000°C, these atoms become ionized. The gas in this stage is termed plasma.

Parameter	Level
Velocity of plasma jet	500 m/s
Material removal rate	150 cm^3/min
Specific energy	100 $W/(cm^3 \cdot min)$
Power range	2–200 kW
Voltage	30–250 V
Current	Up to 600 A
Machining speed	0.1–7.5 m/min
Maximum plate thickness	200 mm

Plasma Beam Machining (PBM)

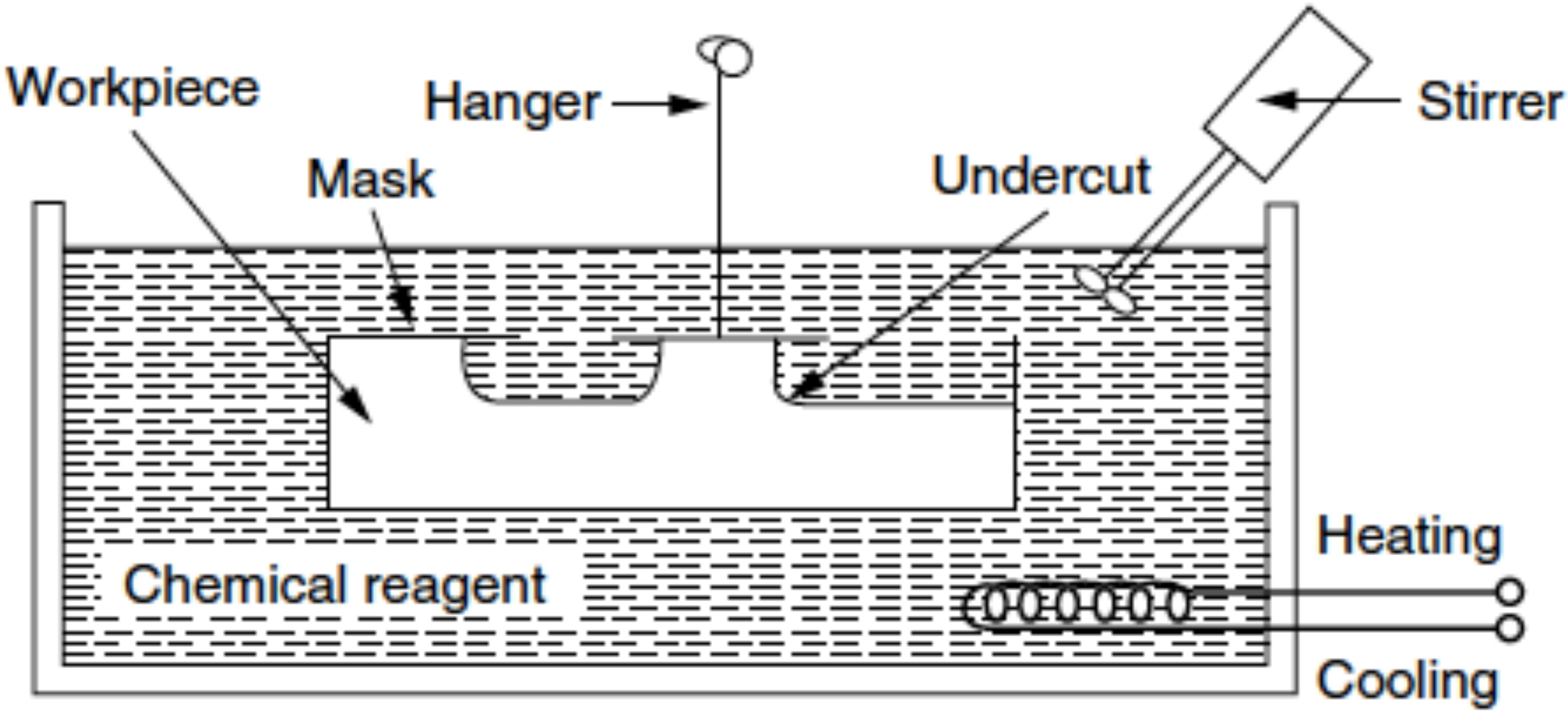
The temperature, in the narrow orifice around the cathode, reaches 28,000°C, which is enough to produce a high-temperature plasma arc. Under these conditions, the metal being machined is very rapidly melted and vaporized.



Chemical Machining (CHM)

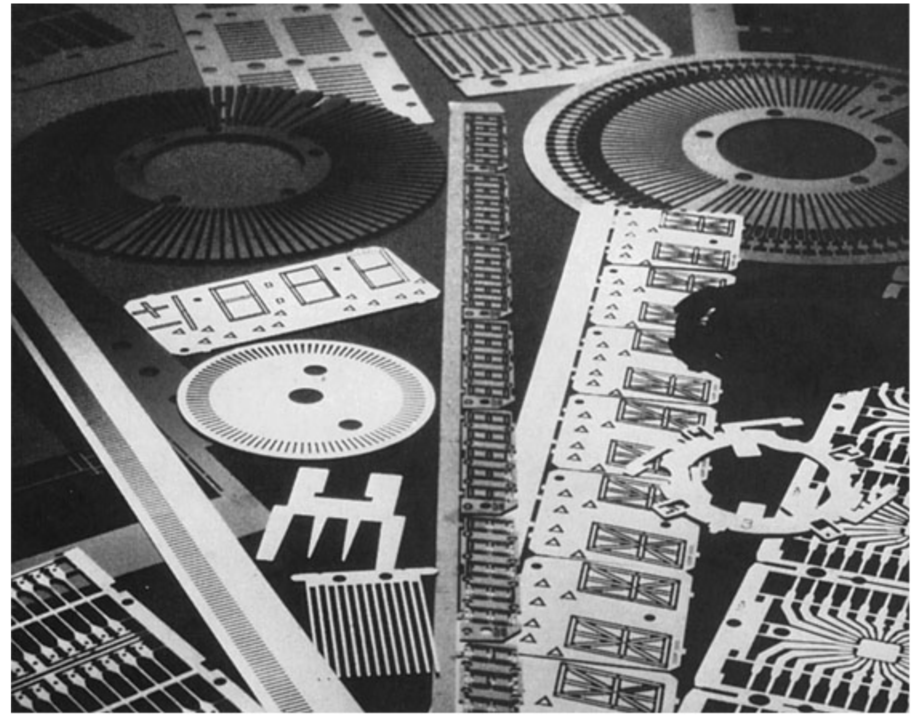
- Chemical machining, basically an etching process, is the oldest nontraditional machining process.
- Material is removed from a surface by chemical dissolution using chemical reagents, or etchants, such as acids and alkaline solutions.
- The workpiece is immersed in a bath containing an etchant. The area that is not required to be etched is masked with "cut and peel" tapes, paints, or polymeric materials.
- In chemical milling, shallow cavities are produced on plates, sheets, forgings, and extrusions for overall reduction of weight (e.g., in aerospace industry). Depths of removal can be as much as 12 mm.

Chemical Machining (CHM)



CHM setup

Chemical Machining (CHM)



- Typical applications

– Chemical blanking: burr-free etching of printed-circuit boards (PCB), decorative panels, thin sheet-metal stampings, and the production of complex or small shapes.

– Chemical milling: weight reduction of space launch vehicles.

Pros: low setup, maintenance, and tooling costs; small, delicate parts can be machined; suitable for low production runs on intricate designs.

Cons: slow (0.025-0.1 mm/min); surface defects; chemicals can be extremely dangerous to health.