Non-Conventional Machining Processes
Non-Conventional Machining

Manufacturing processes can be broadly divided into two groups:

Primary manufacturing processes: Provide basic shape and size

Secondary manufacturing processes: Provide final shape and size with tighter control on dimension, surface characteristics
Non-Conventional Machining

Material removal processes once again can be divided into two groups

Conventional Machining Processes

Non-Traditional Manufacturing Processes or non-conventional Manufacturing processes
Non-Conventional Machining

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.

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
Non-Conventional Machining

Non-conventional manufacturing 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 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.
Non-Conventional Machining

The major characteristics of Non-conventional machining:

In NCM, 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

In NCM, 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.
Non-Conventional Machining

Mostly NCM 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.
Classification of Non-Conventional Machining

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)
Continued

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)
Needs for Non-Conventional Machining

Extremely hard and brittle materials or Difficult to machine materials

When the workpiece is too flexible or slender to support the cutting or grinding forces.

When the shape of the part is too complex.

Intricate shaped blind hole – e.g. square hole of 15 mmx15 mm with a depth of 30 mm
Deep hole with small hole diameter – e.g. φ 1.5 mm hole with l/d = 20

Machining of composites.
In Abrasive Jet Machining (AJM), abrasive particles are made to impinge on the work material at a high velocity. The high velocity abrasive particles remove the material by micro-cutting action as well as brittle fracture of the work material.
Abrasive Jet Machining

In AJM, generally, the abrasive particles of around 50 μm grit size would impinge on the work material at velocity of 200 m/s from a nozzle of I.D. of 0.5 mm with a stand off distance of around 2 mm. The kinetic energy of the abrasive particles would be sufficient to provide material removal due to brittle fracture of the work piece or even micro cutting by the abrasives.
Abrasive Jet Machining

AJM set-up
Ablasive Jet Machining

Process Parameters and Machining Characteristics

**Ablasive:** Material – $\text{Al}_2\text{O}_3$ / SiC
- Shape – irregular / spherical
- Size – 10 ~ 50 μm
- Mass flow rate – 2 ~ 20 gm/min

**Carrier gas:** Composition – Air, $\text{CO}_2$, $\text{N}_2$
- Density – Air ~ 1.3 kg/m³
- Velocity – 500 ~ 700 m/s
- Pressure – 2 ~ 10 bar
- Flow rate – 5 ~ 30 lpm

**Ablasive Jet:** Velocity – 100 ~ 300 m/s
- Mixing ratio – mass flow ratio of abrasive to gas
- Stand-off distance – 0.5 ~ 5 mm
- Impingement Angle – $60^\circ$ ~ $90^\circ$

**Nozzle:** Material – WC
- Diameter – (Internal) 0.2 ~ 0.8 mm
- Life – 10 ~ 300 hours
Abrasive Jet Machining

NTD = Nozzle Tip Distance

7 degrees
Ultrasonic Machining

USM for machining brittle work material

Material removal primarily occurs due to the indentation of the hard abrasive grits on the brittle work material.

Other than this brittle failure of the work material due to indentation some material removal may occur due to free flowing impact of the abrasives against the work material and related solid-solid impact erosion,

Tool’s vibration – indentation by the abrasive grits.

During indentation, due to Hertzian contact stresses, cracks would develop just below the contact site, then as indentation progresses the cracks would propagate due to increase in stress and ultimately lead to brittle fracture of the work material under each individual interaction site between the abrasive grits and the workpiece.

The tool material should be such that indentation by the abrasive grits does not lead to brittle failure.

Thus the tools are made of tough, strong and ductile materials like steel, stainless steel and other ductile metallic alloys.
Ultrasonic Machining

Process variables:
Amplitude of vibration ($a_0$) – 15 – 50 μm
Frequency of vibration ($f$) – 19 – 25 kHz
Feed force ($F$) – related to tool dimensions
Feed pressure ($p$)
Abrasive size – 15 μm – 150 μm
Abrasive material – Al2O3
  - SiC
  - B4C
  - Boronsilicarbide
  - Diamond
  - Flow strength of work material
  - Flow strength of the tool material
  - Contact area of the tool – $A$
  - Volume concentration of abrasive in water slurry – $C$
Ultrasonic Machining

Ultrasonic vibration (20,000 Hz) of very small amplitudes (0.04-0.08 mm) drive the form tool (sonotrode) of ductile material (usually soft steel)

An abrasive slurry is flowed through the work area

The workpiece is brittle in nature (i.e. glass)

The workpiece is gradually eroded away.
USM Equipment

- Transducer
- Horn
- Workpiece
- Feed motion
- Slurry to machining zone
- Return slurry
- Slurry pump
- Slurry tank
Waterjet and Abrasive Waterjet (AWJ) Cutting
Abrasive Waterjet and Waterjet examples
Abrasive Water Jet

High pressure water (20,000-60,000 psi)

Educt abrasive into stream

Can cut extremely thick parts (5-10 inches possible)
  - Thickness achievable is a function of speed
  - Twice as thick will take more than twice as long

Tight tolerances achievable
  - Current machines 0.002” (older machines much less capable ~ 0.010”)

Jet will lag machine position, so controls must plan for it
Components of AWJM

**Catcher**

(a) water basin  
(b) steel/WC/ceramic balls  
(c) catcher plates (TiB$_2$)
Chemical Machining (Chemilling)

Applications:
- Aerospace industry
- Engraving
- Circuit boards

A maskant is applied over areas you don’t want to machine
- Photochemical methods
- Apply maskant to entire surface and use laser to cut

Place the entire part in a chemical bath (acid or alkali depending upon the metal)

Control temperature and time of exposure to control material removal
Electro-Chemical Machining (ECM)

Works on the principle of electrolysis – accelerated chemilling

Die is progressively lowered into workpiece as workpiece is dissociated into ions by electrolysis

Electrolytic fluid flows around workpiece to remove ions and maintain electrical current path

Low DC voltage, very High current (700 amps)
Electrochemical grinding

Combines electrochemical machining with conventional grinding

- Grinding wheel is the cathode
- Metal bonded wheel with diamond or Al2O3 abrasive
- Majority of material removal from electrolytic action (95%) therefore very low wheel wear
- Much faster than conventional grinding
Electrode Discharge Machining (EDM)

Direct Competitor of ECM – much more common than ECM

The tool acts as a cathode (typically graphite) is immersed in a Dielectric fluid with conductive workpiece

DC voltage (~300V) is applied. As voltage builds up over gap between workpiece and tool, eventually you get dielectric breakdown (sparking at around 12,000 deg F)

The sparking erodes the workpiece in the shape of the tool

The tool is progressively lowered by CNC as the workpiece erodes

Cycle is repeated at 200,000-500,000 Hz

Dielectric:
- Cools tool and workpiece
- Flushes out debris from work area
Die Sinker vs. Wire EDM

Die sinker EDM
- The die sinks into the part as it sparks away the workpiece
- Most common Injection molding die process

Wire EDM
- The electrode is a wire that traverses through the part
- Common for Extrusion Dies
Laser Beam Machining

Lasers are high intensity focused light sources

- CO2
  - Most widely used
  - Generally more powerful than YAG lasers
  - Cutting operations commonly

- Nd:YAG (Neodymium ions in an Yttrium Aluminum Garnet)
  - Less powerful
  - Etching/marking type operations more commonly

Limited in depth of cut (focus of light)

Would limit workpiece to less than 1 inch (< ½” typically)
Wire EDM (not shown), Die Sinker EDM, Anodized
Different Part - Wire EDM – profiling and drilling
Case Study Three

1. CNC Milling
2. Setup on wire EDM
3. QA After wire EDM
4. Grinding a face on the part
Setup of Die Sinker EDM

1. Locating parts relative to machine

2. Locating the electrode relative to parts setup
Die Sinker in action and finished product
Overall Machining Tolerances and Surface Roughness

**Surface Roughness (Rₐ, μin.)**

- 2000, 500, 125, 32, 8, 4, 2, 1

**Tolerances, ±0.001 in.**

- 100, 50, 20, 10, 5, 2, 1, 0.5, 0.2, 0.1, 0.05

**Notes:**
- (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.