Module III: Material Removal Processes

Material removal processes — also known as **machining processes** — involve removing material from a workpiece to obtain the desired shape, size, surface finish, and accuracy. These processes are critical in manufacturing components that require tight tolerances and fine finishes.

1. Common Material Removal (Machining) Processes

a) Turning

- **Description**: A workpiece rotates while a single-point cutting tool removes material.
- **Machine**: Lathe
- **Operations**: Facing, straight turning, taper turning, threading.
- **Applications**: Shafts, rods, disc-type components.

b) Drilling

- **Description**: A multi-point tool (drill bit) rotates to cut a round hole in the workpiece.
- **Machine**: Drill press or CNC machine
- **Types**: Drilling, reaming, counterboring, countersinking, tapping.
- **Applications**: Bolt holes, engine blocks, tool bodies.

c) Milling

- **Description**: A rotary multipoint cutter removes material from a stationary workpiece.
- **Machine**: Milling machine (horizontal or vertical)
- **Types**: Peripheral (slab) milling, face milling, end milling.
- **Applications**: Flat surfaces, slots, gear teeth, complex contours.

d) Grinding

- **Description**: Removes very fine material using abrasive particles bonded into a rotating wheel.
- **Machine**: Surface grinder, cylindrical grinder, centerless grinder.
- **Application**: Achieving fine surface finish and precise dimensions.
- **Used For**: Hard materials, tight tolerances.

e) Other Finishing Processes

- **Lapping**: Creates high-precision flat surfaces using an abrasive slurry.
- **Honing**: Improves surface finish of bores (e.g., engine cylinders).
- **Superfinishing**: Uses very fine abrasives for an ultra-smooth finish.
- **Polishing/Buffing**: Creates a shiny appearance using soft wheels and polishing compounds.

2. Types of Cutting Tools

a) Single-Point Cutting Tools

- **Used In**: Lathe operations (turning, facing, etc.)
- **Structure**: One cutting edge.
- **Materials Used**: HSS, carbide, ceramic.

b) Multi-Point Cutting Tools

- **Used In**: Milling, drilling, grinding.
- **Examples**:
  - Drill bits (2–4 flutes)
  - Milling cutters (multiple edges)
  - Grinding wheels (abrasive grits)

3. Cutting Tool Materials

Common Tool Materials:

Material	Properties	Applications
High-Speed Steel (HSS)	Tough, moderate wear resistance	General-purpose tools
Carbides (WC-Co)	Harder, higher cutting speed	Milling, turning of hard materials
Ceramics (Al_2O_3, Si_3N_4)	Very high hardness, wear resistance	High-speed finishing (hard steels)
Cubic Boron Nitride (CBN)	Second hardest after diamond	Machining hardened steels
Polycrystalline Diamond (PCD)	Hardest material	Non-ferrous materials, composites

Selection of tool material depends on:

- Workpiece material
- Cutting speed
- Required tool life and finish

4. Cutting Fluids

Functions:

- Reduce **friction** and **wear**.
- **Cool** the cutting zone.
- **Flush away chips**.
- Prevent **corrosion**.

Types:

- **Coolants**: Water-based fluids (high cooling, low lubrication).
- **Lubricants**: Oil-based fluids (high lubrication, lower cooling).
- **Emulsions**: Mixture of water and oil (balanced properties).
- **Dry machining**: For eco-friendly operations where lubricant is avoided.

5. Key Performance Metrics in Machining

a) Material Removal Rate (MRR)

- The volume of material removed per unit time.
- **Formula (for turning)**:

  $$MRR = V \cdot f \cdot d \quad (\mathrm{mm}^3/\mathrm{min})$$

  Where:
  V = cutting speed (mm/min),
  f = feed rate (mm/rev),
  d = depth of cut (mm)

b) Surface Finish

- Specifies the micro-level smoothness of the part.
- Affected by:
  - Tool geometry
  - Feed rate
  - Speed
  - Tool wear
  - Vibration and chatter

Surface roughness is measured in **Ra (µm)** — lower signifies smoother surface.

c) Dimensional Accuracy

- How close the machined part dimensions are to the intended shape.
- Related to:
  - Machine precision
  - Tool wear
  - Fixturing

d) Surface Integrity

- Refers to microstructure, hardness, stress state, and surface defects (burns, micro-cracks).
- Machining may affect surface hardness or induce tensile/compressive residual stresses.
- Important in high-performance applications (aerospace, medical).

6. Machinability

Machinability refers to how easily a material can be machined to the desired quality and tool life.

Factors Determining Machinability:

- **Chip formation**: Continuous vs. discontinuous.
- **Tool wear rate**: Slower is better.
- **Surface finish**: Ability to achieve smooth surfaces.
- **Power consumption**: Lower is better.
- **Force and temperature**: Lower values are favorable.

Rank of Selected Materials by Machinability (approximate):

Material	Machinability (relative)
Free-cutting steel	Excellent (~100%)
Aluminum alloys	Excellent
Low-carbon steel	Good
Stainless steel	Fair to poor
Titanium alloys	Poor
Hardened tool steels	Very poor

Summary Table

Process	Tool Type	Speed	Surface Finish	Typical Uses
Turning	Single-point	Medium	Good	Cylindrical parts, shafts
Drilling	Multi-point	Medium	Moderate	Holes, tapping, countersinking
Milling	Multi-point	High	Good	Slots, surfaces, profiles
Grinding	Abrasive grits	Very high	Excellent	Fine finishes, hardened parts
Lapping	Free abrasives	Low	Ultra-smooth	Optical, tooling dies

Conclusion

Material removal processes allow for high precision and refined finishing of components essential in most manufacturing sectors such as automotive, aerospace, medical, and tooling industries. Selection of the appropriate process, tools, and parameters — based on material properties, dimensional requirements, and production volumes — ensures high-quality output, efficiency, and economy.