TA202A: Introduction to Manufacturing Processes

N. Sinha
Department of Mechanical Engineering
IIT Kanpur
Email: nsinha@iitk.ac.in
Manufacturing

Derived from two Latin words *manus* (hand) and *factus* (make); the combination means “made by hand”

Present perspective: involves making products from raw material by various processes, machinery and operations following a well-organized plan for each activity required.

Technological

Economic
Manufacturing Activity Should Be Responsive To..

- Meet design requirement (Diameter, length, surface finish, tolerances, etc.).
- Most economic method to minimize cost

- From design to assembly: the quality should be built into the product at each stage.
- Production method should be flexible: meet varying demand (quantity, types, delivery date, etc.).

- **Manufacturing Organization**: strive for higher productivity and optimum use of all its resources → material, men, machines, money (4M)
DESIGN AND MANUFACTURING OF A PRODUCT

1. YOU CAN NOT MAKE IF YOU CAN NOT MEASURE
2. YOU CAN NOT DESIGN IF YOU CAN NOT MANUFACTURE

- Important issues related to Design and MANUFACTURING.
  - Ex: Paper clip (clip shape: square or round, wire size: dia, length)
  - Functional requirement: to hold papers with sufficient clamping force.

- Material issues:
  - Type of material. Stiffness (deflection/force) & strength (yield stress: stress to cause permanent deformation. If it is too strong, a lot of force will be required but if it is too weak, it may not work in holding the papers etc).

- Aesthetic issues:
  - Style, appearance and surface finish of the clip. Corrosion resistance is also required (subjected to moisture and other environmental attack).

- Production issues:
  - Quantity to be produced: tens, hundreds, ……, millions
  - Can the wire be bent without cracking/breaking?
  - Smooth edge or burr (undesirable): paper finger
IN CASE OF METALLIC PARTS, STEPS FOLLOWED

ORE → EXTRACT METAL → MELT IN A FURNACE → CASTING → CUT IN PROPER SIZES (LOG) → TRANSPORT TO TRADER

![Diagram of the process]

EXPLAIN THE ABOVE STEPS WITH MACHINING CONDITIONS AND TOOLS’ DETAILS, IT WILL BE CALLED A PROCESS PLAN.

MACHINING CONDITIONS: f, d, v. (cutting fluid / dry cutting)
Tool’s Details: Tool material, tool angles.

What has gone into?
· Value addition
· Conversion of raw material into useful product → Manufacturing by performing different operation

Final product: Weight 3 kg, Cost – Rs 500/. RAW MATERIAL COST Rs. 60/ PER Kg
Hence a designer should be well acquainted with

✓ Materials and their properties
✓ Manufacturing processes and capabilities
  ➢ Related manufacturing machines and equipments
  ➢ Assembly and inspection procedures
✓ Finishing and surface treatment processes
✓ Heat treatment or bulk property enhancing processes
Materials in Manufacturing

- Their chemistries are different, and their mechanical and physical properties are different.
- These differences affect the manufacturing processes that can be used to produce products from them.
1. Metals

Usually *alloys*, which are composed of two or more elements, at least one of which is metallic. Two basic groups:

1. Ferrous metals - based on iron, comprises about 75% of metal tonnage in the world:
   - Steel and cast iron

2. Nonferrous metals - all other metallic elements and their alloys:
   - Aluminum, copper, nickel, silver, tin, etc.
Charging a basic oxygen furnace in steelmaking: molten pig iron is poured. Temperatures are around 1650°C (3000°F).
1. Metals
1. Metals

Applications

- Electrical wiring
- Structures: buildings, bridges, etc.
- Automobiles: body, chassis, springs, engine block, etc.
- Airplanes: engine components, fuselage, landing gear assembly, etc.
- Trains: rails, engine components, body, wheels
- Machine tools: drill bits, hammers, screwdrivers, saw blades, etc.
- Magnets

Examples

- Pure metal elements (Cu, Fe, Zn, Ag, etc.)
- Alloys (Cu-Sn=bronze, Cu-Zn=brass, Fe-C=steel, Pb-Sn=solder)
- Intermetallic compounds (e.g. Ni$_3$Al)
2. Ceramics

Compounds containing metallic (or semi-metallic) and nonmetallic elements.

- Typical nonmetallic elements are oxygen, nitrogen, and carbon
- For processing, ceramics divide into:
  1. Crystalline ceramics – includes:
     - Traditional ceramics, such as clay, and modern ceramics, such as alumina (Al₂O₃)
  2. Glasses – mostly based on silica (SiO₂)
2. Ceramics

Distinguishing features

- Composed of a mixture of metal and nonmetal atoms
- Lower density than most metals
- Stronger than metals
- Low resistance to fracture: low toughness or brittle
- Low ductility or malleability
- High melting point
- Poor conductors of electricity and heat
- Except for glasses, atoms are regularly arranged

- While metals react readily with chemicals in the environment and have low application temperatures in many cases, ceramics do not suffer from these drawbacks.
- Ceramics have high-resistance to environment as they are essentially metals that have already reacted with the environment, e.g. Alumina ($\text{Al}_2\text{O}_3$) and Silica ($\text{SiO}_2$, Quartz).
- Ceramics are heat resistant. Ceramics form both crystalline and non-crystalline phases because they can be cooled rapidly from the molten state to form glassy materials.
2. Ceramics

Applications
- Electrical insulators
- Abrasives
- Thermal insulation and coatings
- Windows, television screens, optical fibers
- Corrosion resistant applications
- Biocompatible coatings (fusion to bone)
- Magnetic materials (audio/video tapes, hard disks, etc.)
- Night-vision

Examples
- Simple oxides (SiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, MgO)
- Mixed-metal oxides (SrTiO$_3$, MgAl$_2$O$_4$, YBa$_2$Cu$_3$O$_{7-x}$)
- Nitrides (Si$_3$N$_4$, AlN, GaN, BN, and TiN, which are used for hard coatings)
3. Polymers

- Compound formed of repeating structural units called *mers*, whose atoms share electrons to form very large molecules.

- Polymer usually consists of carbon plus one or more elements such as hydrogen and nitrogen.

Polyethylene: (the *mer* unit is $\text{C}_2\text{H}_4$)  
Polypropylene: (the *mer* unit is $\text{C}_3\text{H}_6$)
3. Polymers

Distinguishing features

- Composed primarily of C and H (hydrocarbons).
- Low melting temperature.
- Most are poor conductors of electricity and heat.
- Many have high plasticity.
- A few have good elasticity.
- Some are transparent, some are opaque.

- Polymers are attractive because they are usually lightweight and inexpensive to make, and usually very easy to process, either in molds, as sheets, or as coatings.

- Most are very resistant to the environment.

- They are poor conductors of heat and electricity, and tend to be easy to bend, which makes them very useful as insulation for electrical wires.
3. Polymers

Three categories:
1. Thermoplastic polymers - can be subjected to multiple heating and cooling cycles without substantially altering molecular structure
2. Thermosetting polymers - molecules chemically transform into a rigid structure – cannot reheat
3. Elastomers - shows significant elastic behavior

Applications and Examples
Adhesives and glues, Containers, Moldable products (computer casings, telephone handsets, disposable razors), Clothing and upholstery material (vinyls, polyesters, nylon), Water-resistant coatings (latex), Biodegradable products (corn-starch packing “peanuts”), Biomaterials (organic/inorganic interfaces), Liquid crystals, Low-friction materials (teflon), Synthetic oils and greases, Gaskets and O-rings (rubber), Soaps and surfactants
4. Composites

Material consisting of two or more phases that are processed separately and then bonded together to achieve properties superior to its constituents

- **Phase** - homogeneous mass of material, such as grains of identical unit cell structure in a solid metal
- Usual structure consists of particles or fibers of one phase mixed in a second phase
- Properties depend on components, physical shapes of components, and the way they are combined to form the final material
4. Composites

In two material system, there are two phases: Primary phase & Secondary phase.
- The primary phase forms the matrix within which the secondary phase is imbedded
- The imbedded phase is also known as dispersed phase or reinforcing phase

Matrix phase: The continuous phase
Purpose is to
- Transfer stress to other phases
- Protect phases from environment
- Classification: MMC, CMC, PMC

Dispersed phase
- Purpose is to enhance matrix properties
- Classification: Fiber (Diameter 0.0025 to 0.13mm), Particle (25 to 300μm), flake (two dimensional particles, size: 0.01 to 1mm)
4. Composites

- Particle-reinforced
  - Large-particle
  - Dispersion-strengthened

- Fiber-reinforced
  - Continuous (aligned)
  - Discontinuous (short)

- Structural
  - Laminates
  - Sandwich panels

- Aligned
- Randomly oriented
4. Composites

Distinguishing features
• Composed of two or more different materials (e.g., metal/ceramic, polymer/polymer, etc.)
• Properties depend on amount and distribution of each type of material
• Collective properties more desirable than possible with any individual material

Applications
• Sports equipment (golf club shafts, tennis rackets, bicycle frames)
• Aerospace materials
• Thermal insulation
• Concrete
• "Smart" materials (sensing and responding)
• Brake materials

Examples
Fiberglass (glass fibers in a polymer); space shuttle heat shields (interwoven ceramic fibers); paints (ceramic particles in latex); tank armor (ceramic particles in metal)
4. Composites

Advantages

- Composites can have a unique property (e.g. Specific strength, specific modulus, improved impact resistance) that is significantly higher than their metal, polymer, and ceramic counterparts.

- Composites can be fabricated to a final product from raw materials eliminating many secondary operations such as machining, shaping, joining etc. (Reduce structural weakness and processing costs).

- Composites can be tailored to have both high strengths and high strains.

Disadvantages

- The costs of the materials are generally higher.

- The nature and the amount of reinforcing elements and matrix will limit the usage of that composite.

- Some environmental concerns (e.g. Solvents, chemical fumes, airborne fibers, etc.) can be involved during the processing of composites.
Shape Memory Materials

**DEFINITION:**

Shape Memory Materials (SMM) are those materials which, after being deformed PLASTICALLY (i.e., PERMANENTLY) at the room temperature into various shapes, return to their original shapes upon heating.

**EXAMPLES:**

Typical Shape Memory Alloys are:
- 55% Ni-45%Ti
- Copper-Aluminum-Nickel
- Copper-Zinc-Aluminum
- Iron-Manganese-Silicon
Shape Memory Materials
CHARACTERISTICS:

- SMM have good ductility, good corrosion resistance, high electrical conductivity
- Behavior of SMM can also be reversible, i.e., shape can switch back and forth upon heating

APPLICATIONS:

Can be used
- To generate motion and/or force in temperature-sensitive actuators
- Eyeglass frames, connectors, clamps and fasteners
**Piezoelectric Materials**

- Piezoelectric crystals are solid ceramic compounds that produce **piezoelectric effects**:

  - Mechanical force induced electric voltage
  - Electric voltage induced mechanical deformation

- Natural piezoelectric crystals are: quartz, tourmaline and sodium potassium tartrate.

- Synthesized crystals are: Rochelle salt, barium titanate and lead zirconate.
Piezoelectricity
A biomaterial can be defined as any substance (other than a drug) or combination of substances synthetic or natural in origin, which can be used for any period of time, as a whole or as a part of a system which treats, augments, or replaces any tissue, organ or function of the body.

Theoretically, any material can be a biomaterial as long as it serves the stated medical and surgical purposes.

Example of Biomaterial

<table>
<thead>
<tr>
<th>Metals</th>
<th>Ceramics</th>
<th>Polymers</th>
</tr>
</thead>
<tbody>
<tr>
<td>316L stainless steel</td>
<td>Alumina</td>
<td>Ultra high molecular weight</td>
</tr>
<tr>
<td>Co-Cr Alloys</td>
<td>Zirconia</td>
<td>polyethylene</td>
</tr>
<tr>
<td>Titanium</td>
<td>Carbon</td>
<td>Polyethylene</td>
</tr>
<tr>
<td>Ti6Al4V</td>
<td>Hydroxyapatite</td>
<td>Polyurethane</td>
</tr>
</tbody>
</table>
Biomaterials

Orthopaedic Applications
- Metallic materials are normally used for load bearing members such as pins and plates and femoral stems etc.
- Ceramics such as alumina and zirconia are used for wear applications in joint replacements.
- Polymers such as ultra high molecular weight polyethylene are used as articulating surfaces against ceramic components in joint replacements.

Dental Applications
- Metallic biomaterials have been used as pins for anchoring tooth implants and as parts of orthodontic devices.
- Ceramics have found uses as tooth implants including alumina and dental porcelains.
- Polymers have are also orthodontic devices such as plates and dentures.
Biomaterials

Cardiovascular Applications
- Many different biomaterials are used in cardiovascular applications depending on the specific application and the design. For instance, carbon in heart valves and polyurethanes for pacemaker leads.

Cosmetic Surgery
- Materials such as silicones have been used in cosmetic surgery.