TA 202A

Lecture 2

Prof. Arvind Kumar
Liquid Metals Group
Mechanical Engineering

Question

- Need of this course?
- Why lab?
- Why theory?

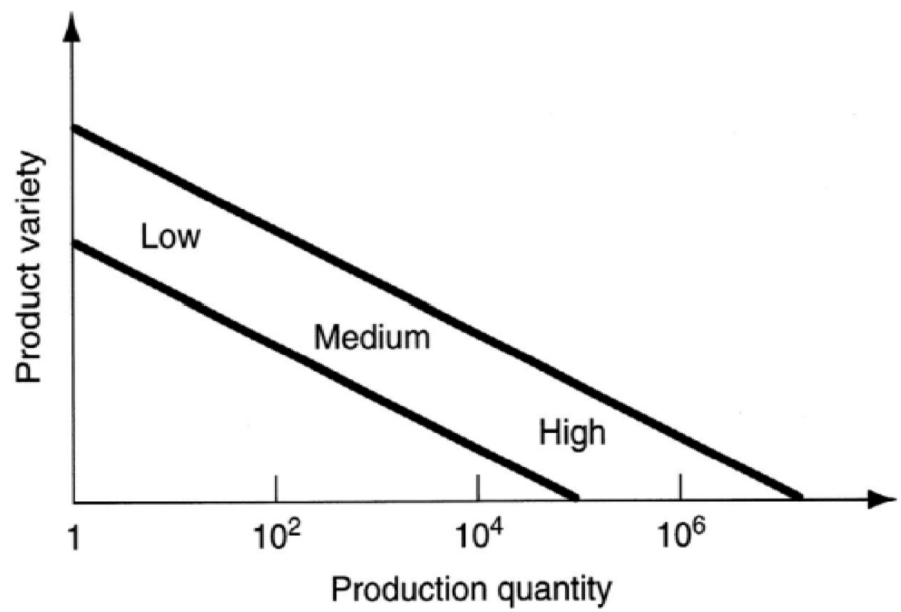
Product Creation Cycle

Design → Material Selection → Process Selection → Manufacture → Inspection → Feedback

Production Quantity and Product Variety

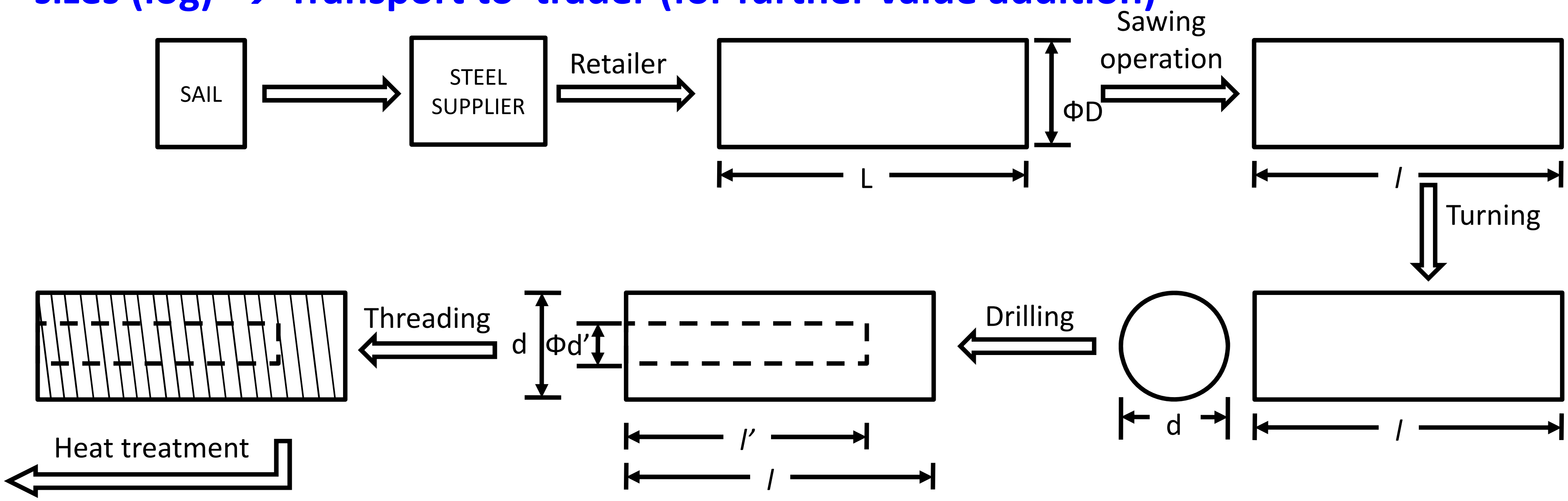
- Soft product variety - small differences between products. Car models made on the same production line

- Hard product variety - products differ substantially. The difference between a car and a truck



Example- metallic parts

Metal ore → Extract metal → Melt in a furnace → Casting → Cut in proper sizes (log) → Transport to trader (for further value addition)



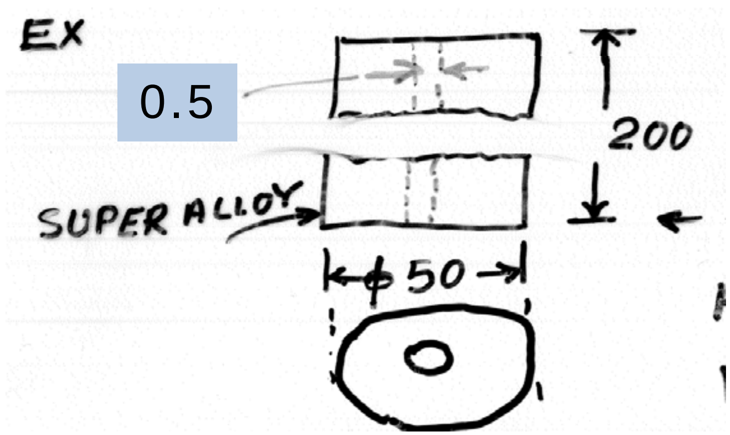
Explain the above steps with machining conditions and tool's details, it will be called a process plan.
Machining conditions: f , d, v. (cutting fluid / dry cutting)
Tool's details: Tool material, tool angles.

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

Design for Manufacturing

- Every designed product : Should be possible to make as a real product → if so, Design and manufacturing both are ***interrelated***
- Design a part such that it meets: Functional requirements, Manufacturing requirements + possible to manufacture with ease and economy



<-- Designed Part

Aspect Ratio = 200/0.5 = 400

SOME QUESTIONS TO CONSIDER?

How to Manufacture so high aspect ratio product?

Will it be economical?

Can you Change the design to make it viable to manufacture economically?

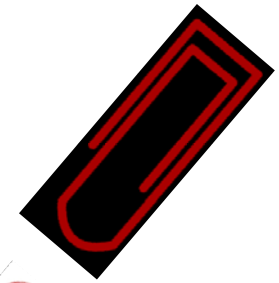
Manufacturing Activity Should Be Responsive To..

- 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).

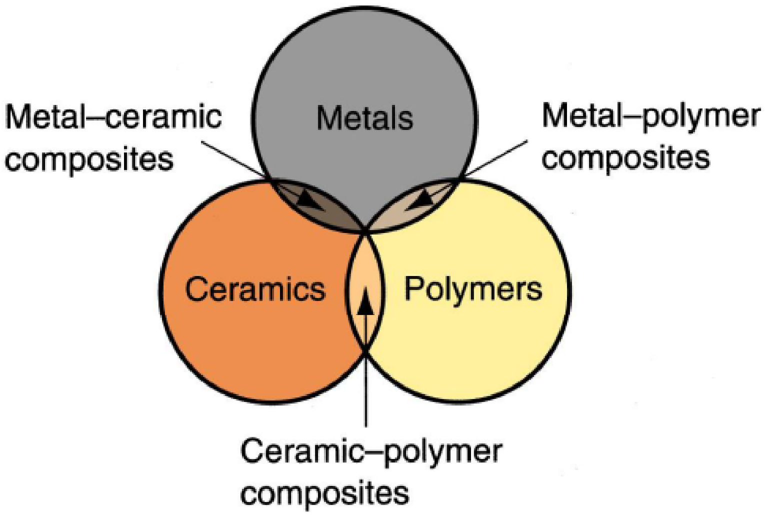
- Production issues:
- Quantity to be produced: tens , hundreds , ……, millions
- Can the wire be bent without cracking/ breaking?
- Smooth edge or burr (undesirable): paper finger

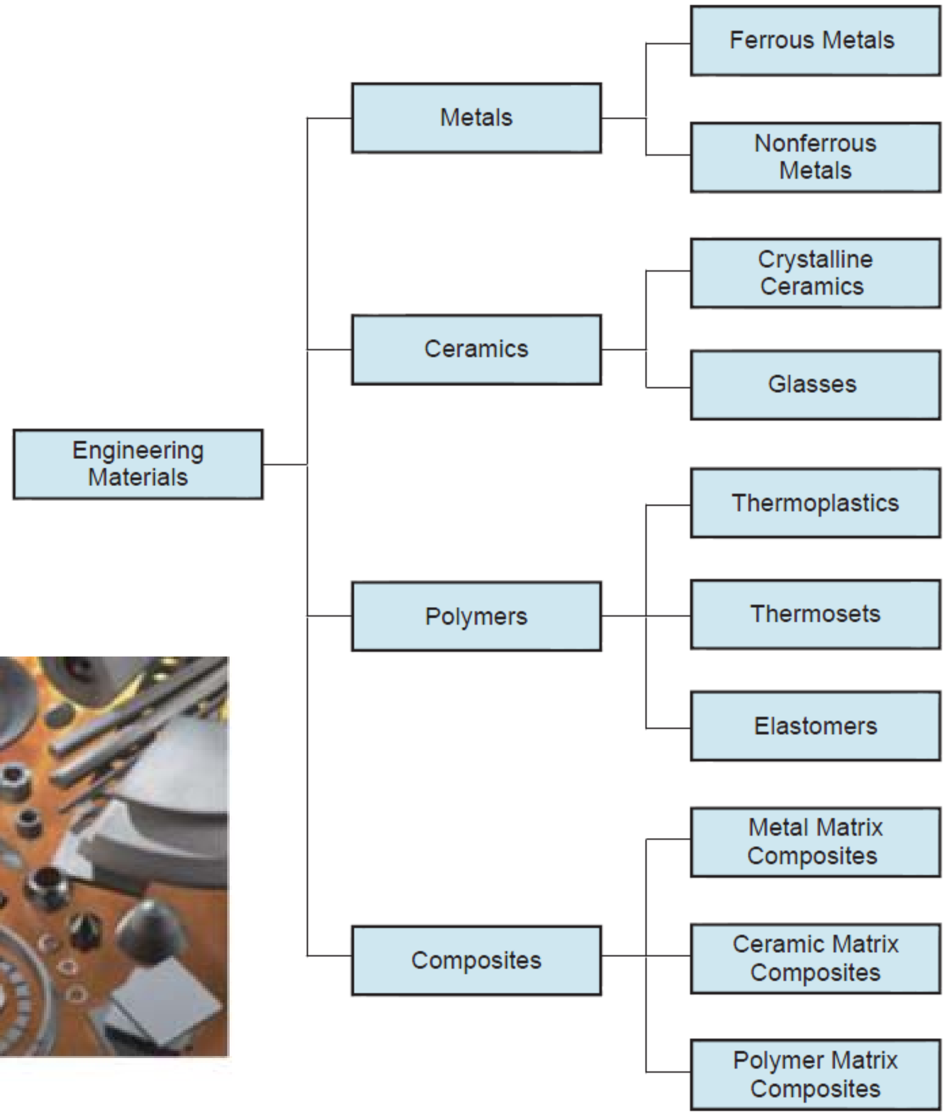
Designer should be well acquainted with

- Materials and their properties
- Manufacturing processes & capabilities
- Related Manufacturing machines & equipments
- Assembly and inspection procedures

➢ General types of materials: Iron and steels, Non-ferrous metals and alloys, Plastics , polymers, Ceramics , glasses, diamonds etc., Composite materials

Materials in Manufacturing





Materials

- ❖ Ferrous metals: Carbon-, alloy-, stainless-, tool-and-die steels
- ❖ Non-ferrous metals: Aluminium, magnesium, copper, nickel, titanium,
- ❖ Superalloys, refractory metals, beryllium, zirconium, low-melting alloys, gold, silver, platinum, etc.
- ❖ Plastics:
  - Thermoplastics (acrylic, nylon, polyethylene, ABS etc.)
  - Thermosets (epoxies, polymides, etc.)
  - Elastomers (rubbers, silicones, polyurethanes etc.)
- ❖ Ceramics, Glasses, Graphite, Diamond, Cubic Boron Nitride
- ❖ Composites: reinforced plastics, metal-, ceramic matrix composites
- ❖ Nanomaterials, shape-memory alloys, high-entropy alloys, superconductors

Properties of Materials

Material Properties

Chemical

- Oxidation
- Corrosion
- Flammability
- Toxicity
- Composition (oxide or compound)

Physical

- Density
- Specific heat
- Melting and boiling point
- Thermal expansion
- Thermal Conductivity
- Electrical
- Magnetic properties

Mechanical

- Strength
- Toughness
- Stiffness
- Hardness
- Ductility
- Malleability
- Brittleness
- Elasticity
- Plasticity
- Fatigue
- Creep

Dimensional

- Size
- Shape

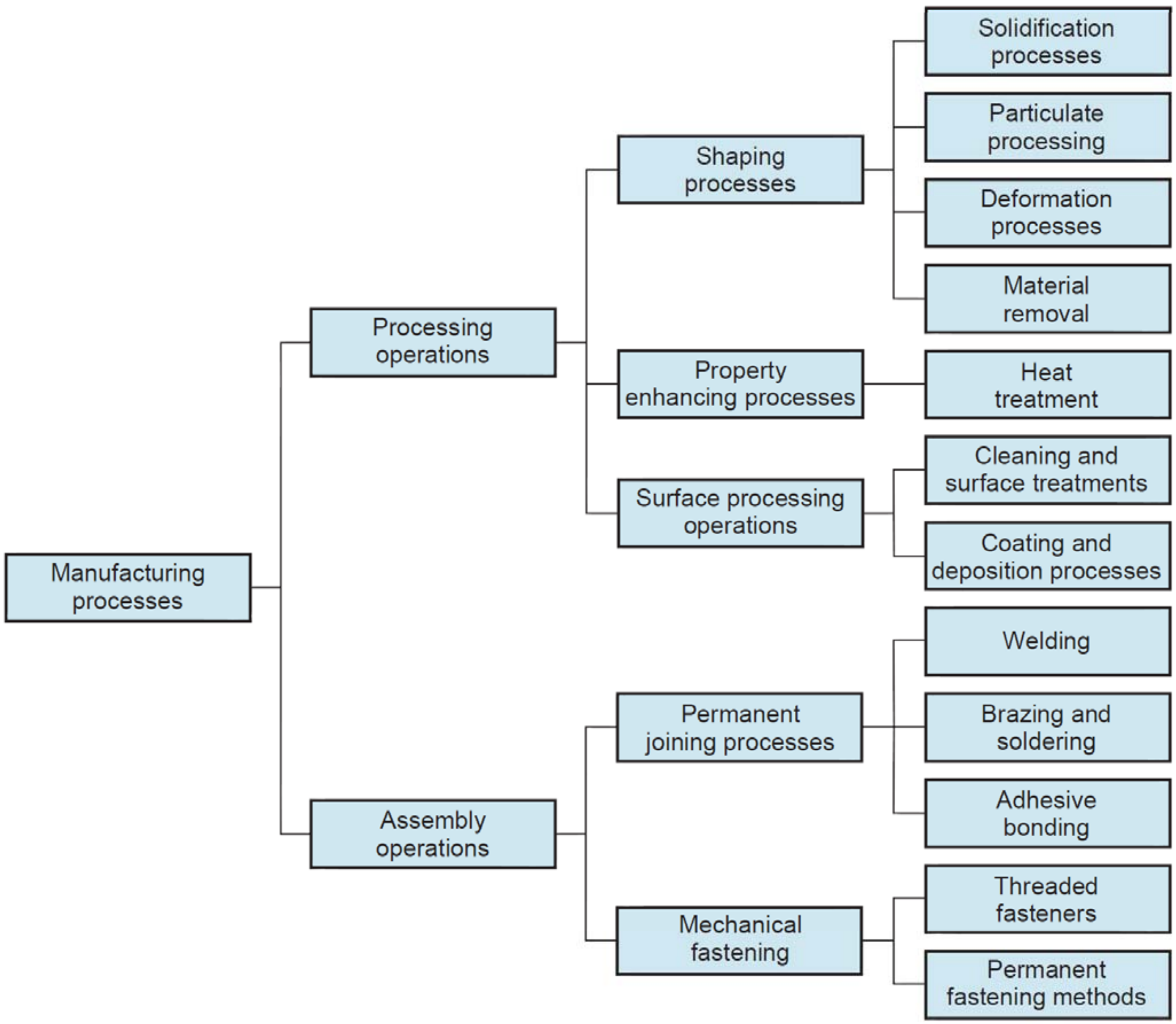
Mechanical properties

- Tensile strength – Tensile strength is defined as the ability of a material to support axial load without rupture and is determined through the tensile test.
- Ductility – The ability of a material to deform under tensile stress. A ductile material is a material that can easily be stretched into a wire when pulled.
- Malleability – The property of metals through which metals can be hammered into thin sheets i.e. it is the ability of material to deform under pressure .
- Brittleness – Breaking or shattering of material when subjected to load.
- Elasticity – The ability of material to regain its normal shape after being stretched or compressed.
- Toughness – The ability of a material to absorb energy and plastically deform without fracturing.
- Hardness– The hardness of a material is a measure of its resistance to penetration by an indenter.
- Machinability– Machinability is a term indicating how the work material responds to the cutting process. Good machinability means that material is cut with good surface finish, long tool life, low force and power requirements, and low cost.

Physical properties

- Specific heat – The heat required to raise the temperature of one kilogram of a substance by one degree centigrade (J/kg K)
- Density – Mass per unit volume expressed (kg/m^3)
- Thermal conductivity –Rate at which heat flows through a given material (W/m K)
- Melting point – A temperature at which a solid begins to melt.
- Electrical conductivity – A measure of how strongly a material conducts the electric current (Ω·m)

Classification of Manufacturing Processes



Classification...contd

- **Primary forming processes (additive or accretion)**
  - Casting and molding processes
  - Powder metallurgy, Additive Manufacturing (Rapid Prototyping)
- **Deforming Processes (Formatives)**
  - Hot working
  - Cold working

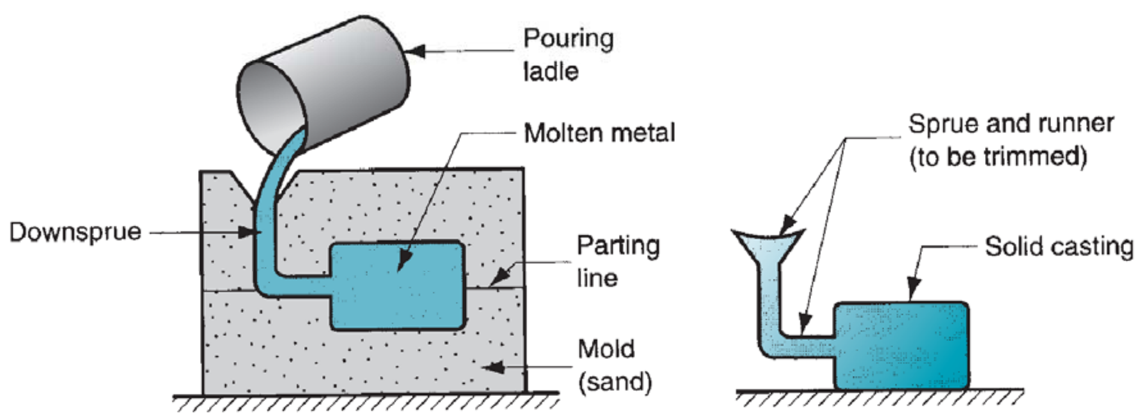
    (Forging, Rolling, Wire drawing, etc.)
- **Material removal processes (subtractive)**
  - Conventional (Turning, Milling, etc.)
  - Advanced machining processes (ECM, EDM, LBM, etc.)
- **Joining and fabrication processes (assembly)**
  - Welding, Riveting, Brazing, Soldering, etc.
- **Finishing and surface treatment processes**
  - Burr removal (deburring)
  - Mechanical cleaning and finishing
  - chemical cleaning
  - Coating
  - Vaporized metal coating
- **Heat treatment or bulk property enhancing processes**
  - Hardening
  - Ductility, toughness and machinability
  - Strengthening

1. Processing Operations

Shaping Processes: Shaping operations alter the geometry of the starting work material by various methods. Ex. casting, forging, and machining

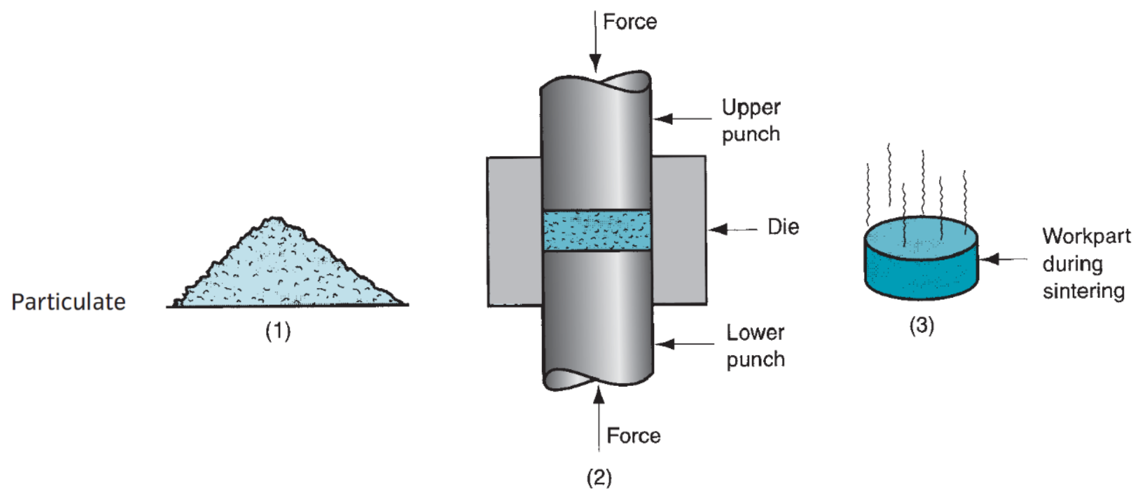
Solidification processes

- Starting material heated liquid or semifluid
- Casting (for metals) or Molding (plastics)



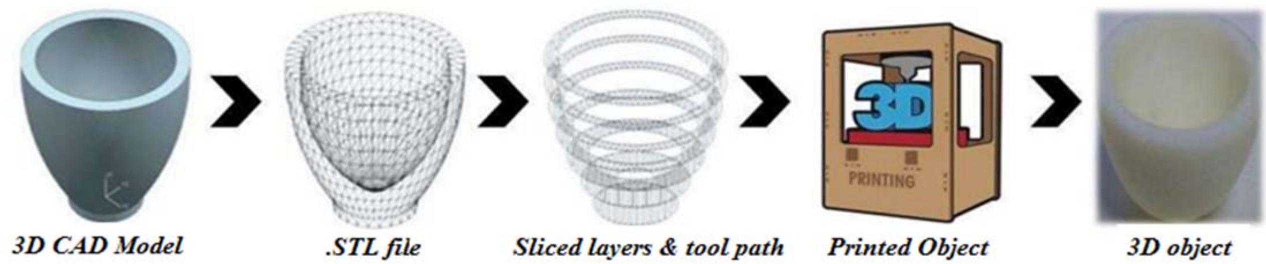
Solidification process: Casting

Particulate processing - starting material consists of powders



Particulate processing: Powder metallurgy

Additive Manufacturing (AM): Making objects layer by a layer from 3D CAD data. Different from material removal in traditional subtractive manufacturing.



What you see is what you Build (WYSIWYB) Process

But, Only theoretically

- Digital 3D design data is used to build up a component in layers by depositing material.
- A layer by layer build up.
- Materials - Metals, plastics, composite.

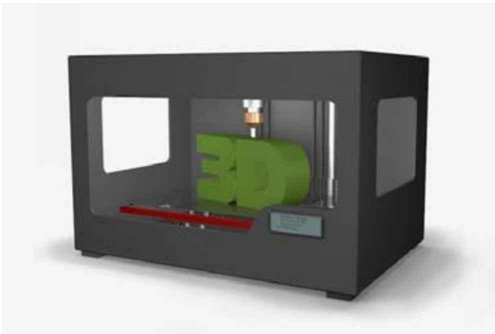
Reality is a bit different !

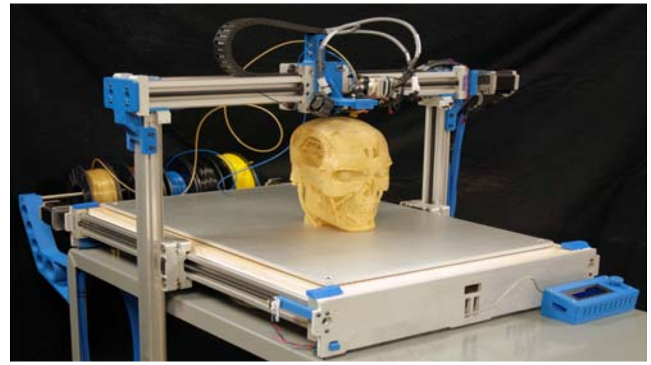
In practice, there are numerous geometrical, handling and material limitations which put restrictions on the building geometries.

Part production in AM

Laser powder interaction

3D Printing Process





Tough Natural Colored Nylon 11

Tough and durable polypropylene-like thermoplastic

Tough Black Nylon 11

Tough, impact and fatigue-resistant black Nylon 11 for prototypes

Biocompatible Nylon 12

Strong, tough biocompatible material

Flame Retardant Nylon 12

Excellent surface finish, reliable fire retardancy and reduced smoke and toxicity

Aluminum-filled Nylon 12
Excellent surface finish and high stiffness with a metallic aesthetic

Glass-filled Nylon 12
Nylon 12 with excellent stiffness and heat resistance

Fiber-reinforced Nylon 12
excellent stiffness and high temperature resistance

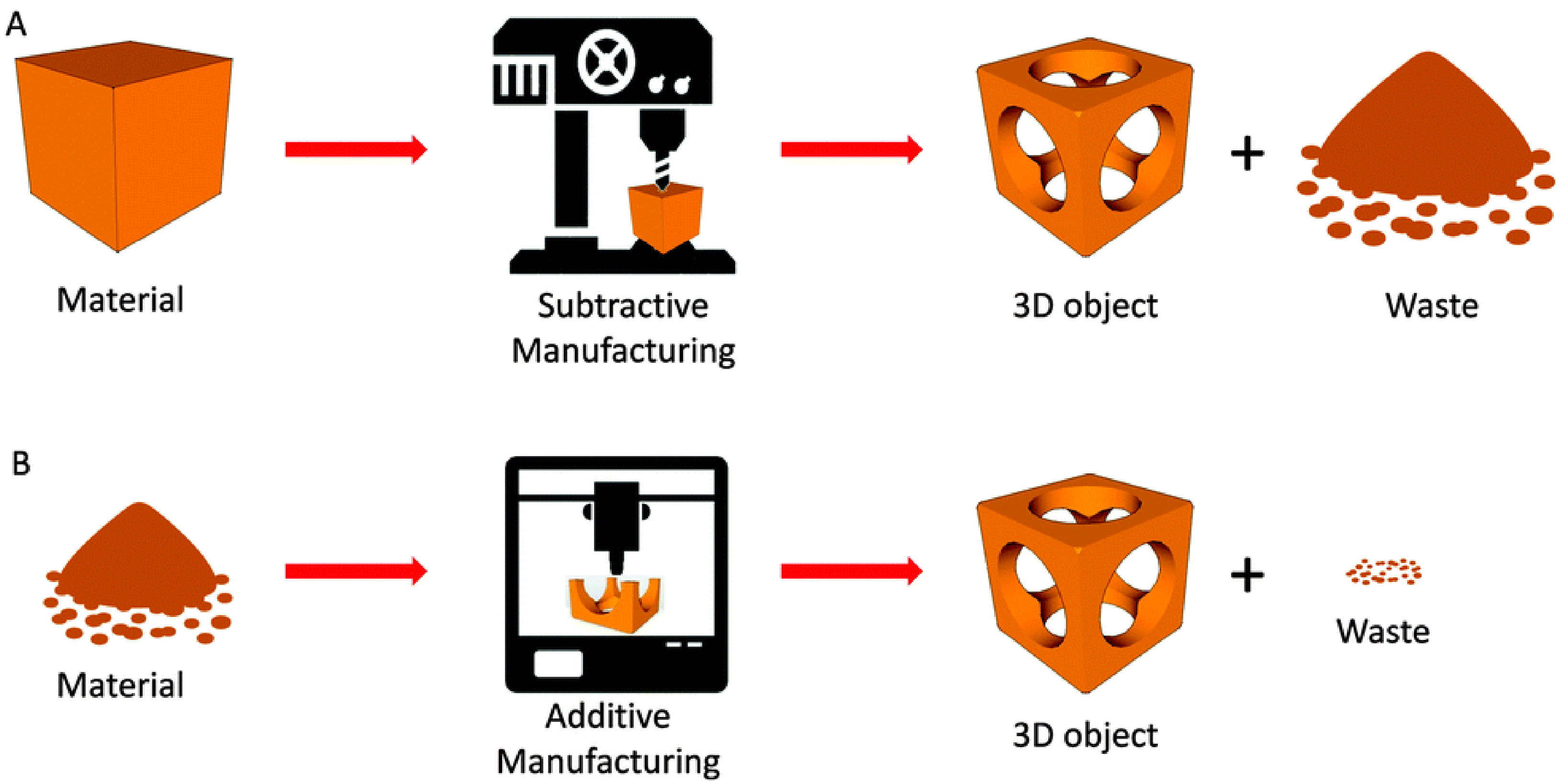
APPLICATIONS

- Production parts
- Automotive design
- Aerospace components
- Jigs / fixtures
- Rigid enclosures / cases

BENEFITS

- Glass-filled Nylon 12 for high strength and heat resistance
- For rugged physical testing and functional use
- Aircraft and automotive end-use parts

Additive vs. Subtractive Manufacturing

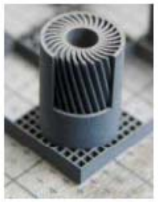


Why AM is growing rapidly ?

Several benefits (concept of Green Manufacturing):

- Much reduced material waste and energy consumption
- Tooling reduction by single machine requirement
- Shortened time-to-market inventory reduction





CAD → SLM → Product

Tooling and Dies

- Prototyping and testing at concept

- **Complex shapes not an issue, lattice structures, lightweighing**

Complex heat exchanger

Hydraulic component with complex internal geometries

Conformal cooling

Product optimization by applying innovative design concepts (wt reduction)

Old design 2 kg

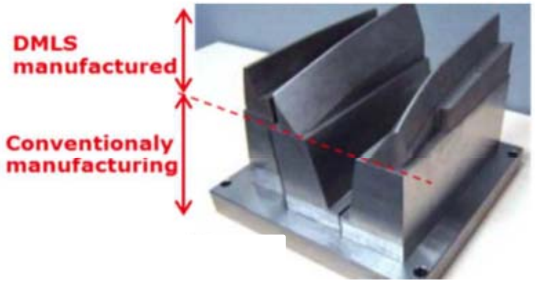
New design 300 g

Bracket used in aircraft (Boeing)

Freedom of Design leads to
Manufacturing for Design **concept**

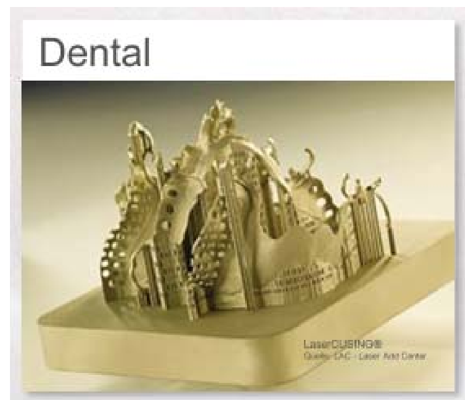
- **Suitable for functionally graded materials, hybrid manufacturing**

Biomedical implants



Current and Potential Industries for Additive Manufacturing

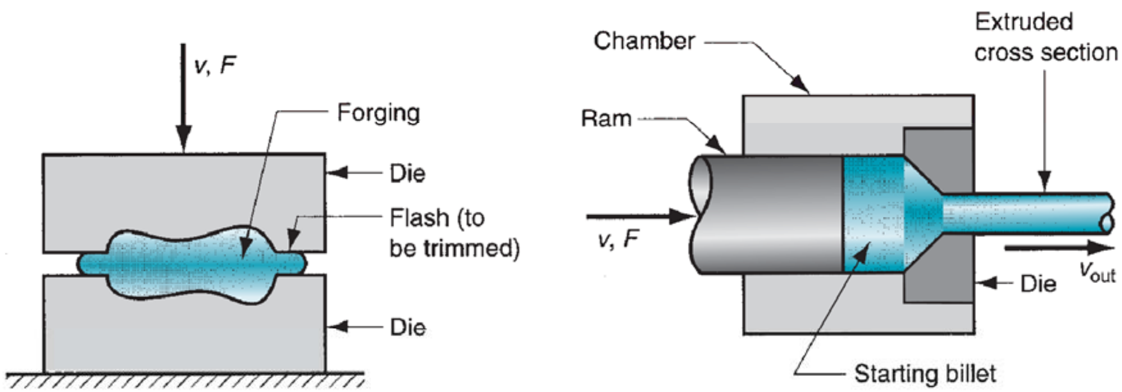
Medical




REPAIR OF WORN PARTS

Deformation processes

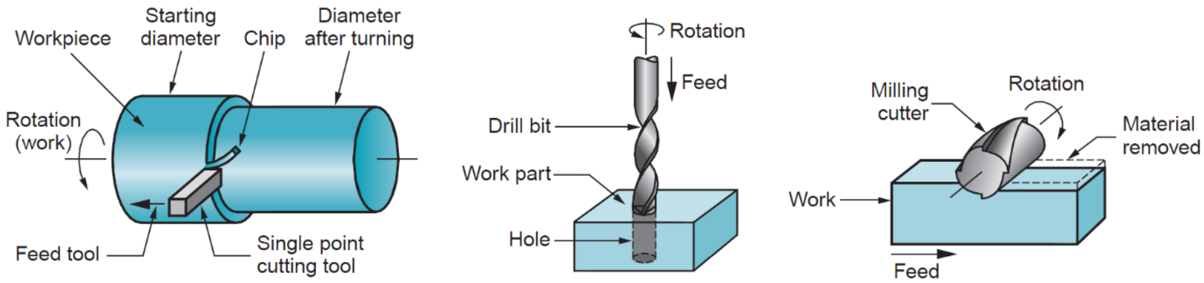
- Starting material is a ductile solid (commonly metal)
- The starting workpart is shaped by the application of forces that exceed the yield strength of the material



Deformation processes: Metal forming

Material removal processes

- Starting material is a ductile or brittle solid
- Remove excess material from the starting workpiece so that the resulting shape is the desired geometry.
- Turning, drilling, and milling



Material removal processes: Machining

Grinding is another common process in this category. Other material removal processes are known as non-traditional processes because they use lasers, electron beams, chemical erosion, electric discharges, and electrochemical energy to remove material rather than cutting or grinding tools.

Waste in Shaping Processes

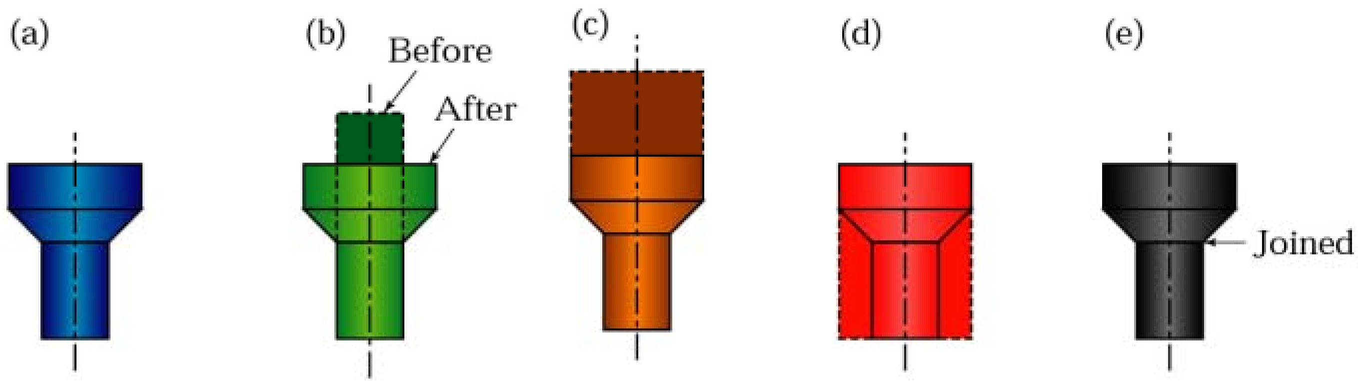
- It is desirable to minimize waste in part shaping
- Material removal processes are wasteful in the unit operations, but casting and particulate processing operations waste little material

Terminology used in shaping processes

- Net shape processes - when most of the starting material is used and no subsequent machining is required

- Near net shape processes - when minimum amount of machining is required

Methods of Making a Simple Part



Various methods of making a simple part: (a) casting or powder metallurgy, (b) forging or upsetting, (c) extrusion, (d) machining, (e) joining two pieces (Mass Addition Process).

2. Property-enhancing operations

Property-enhancing operations add value to the material by improving its physical properties without changing its shape. Heat treatment is the most common example.

- Heat Treatment: Improve physical properties of the material without changing its shape

3. Surface processing operations

Surface processing operations are performed to clean, treat, coat, or deposit material onto the exterior surface of the work. Examples:

- Cleaning and surface treatments
- Coating and thin-film deposition

Selection of manufacturing processes

- **Quantity to be produced (small, medium, large)**
- Shape to be produced (circle, square, rectangle, etc.)
- Material & its properties.
  - Metal or non-metal; electrical conductivity , light reflecting or not,… brittle/ hard/ soft, magnetic / non-magnetic
  - Dimensional and surface finish requirements, tolerance, fits (roughness value), surface finish

$$10^{+0.02}_{-0.02} \qquad 10^{+.1}_{-.1}$$

$$R_a = 1\ \mu m \qquad R_a = 0.1\ \mu m \qquad R_a = 0.01\ \mu m$$

- Cost : (selected mfg. process)
- What will happen if selected material & mfg. process are improper?

Rejection / Failure of the part.

- **When a product will called failed?**
  - Stops functioning
  - Does not function properly
  - Becomes unreliable or unsafe

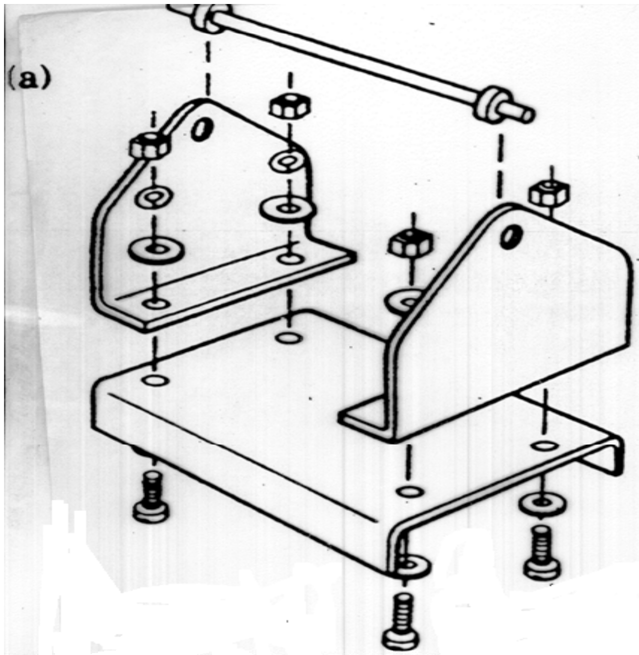
Assembly Operations

Assembly requires consideration of putting parts together

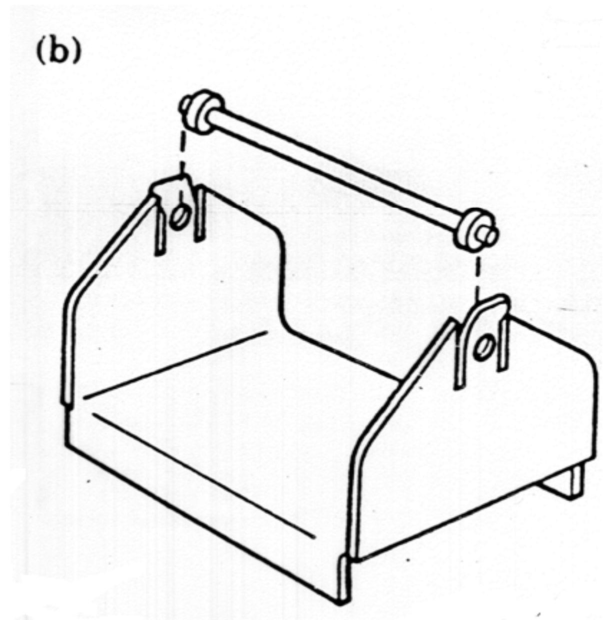
1. Joining processes:
   - Welding
   - Brazing and soldering
   - Adhesive bonding
2. Mechanical assembly:
   - Threaded fasteners (e.g., bolts and nuts, screws)
   - Rivets
   - Interference fits (e.g., press fitting, shrink fits)

> **Design For Assembly**
> - **Important area of manufacturing**
> - **Permit assembly with ease**
> - **Reduce cost of assembling**
>
> **Simplify design by reducing required no of pieces / parts.**

Example of easy assembly



Total no. of parts = 24



Total no. of parts = 2

AN EXAMPLE OF DESIGN FOR ASSEMBLY:
(A) AS DESIGNED, THIS PRODUCT CONSISTS OF MANY COMPONENTS AND TAKES CONSIDERABLE TIME TO ASSEMBLE.
(B) REDESIGNED PRODUCT CONSISTS OF ONLY TWO PARTS AND IS EASY TO ASSEMBLE, EITHER BY HAND OR IN AUTOMATED MACHINERY.

Quality

- Most important aspect of manufacturing
  - Influences marketability & customer satisfaction
- **High quality and low cost :**
  - Quality also mean meeting design specifications.
  - Quality must be built into a product → from the design stage through all subsequent stages of manufacturing & assembly

⬇

Total quality control

Quality also means meeting design specifications of the product

- Customer satisfaction : Are they happy with the quality and price ?

Automation and Computers in Manufacturing

➢ Why automation?

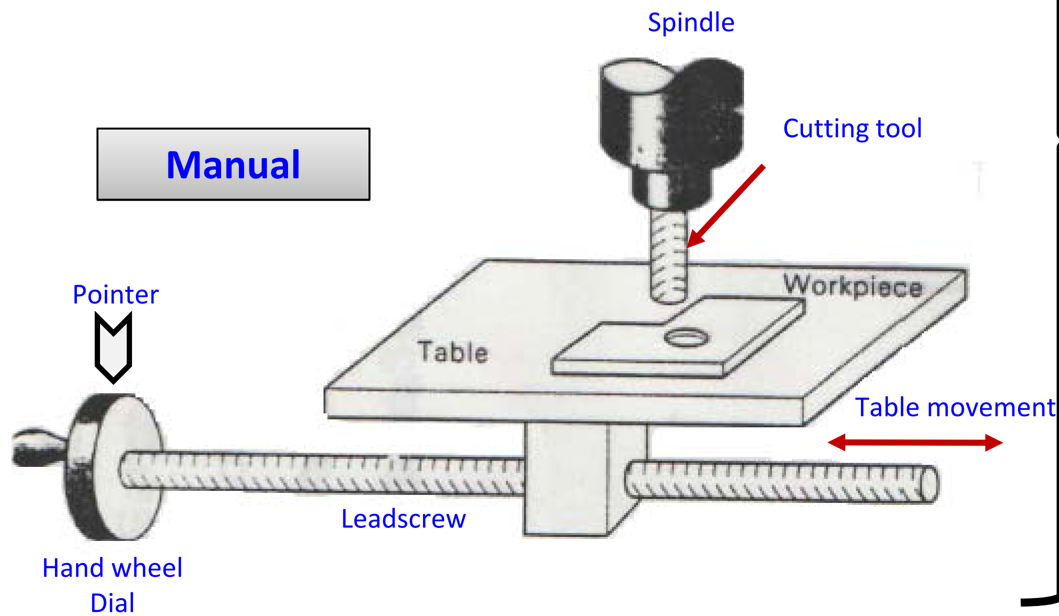
- Improved productivity
- Improved quality
- Minimum cycle time
- Reduced labor cost / hazard

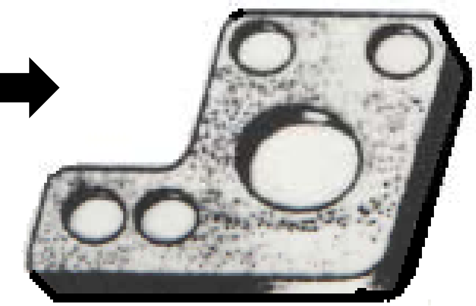
Role of the Computers in Manufacturing

- Computer control of manufacturing processes: NC/CNC
- Optimization of mfg. processes
- Automated material handling system(AGV)
- Automated inspection and testing
- Automated assembly systems
- Robots in manufacturing
    - Reduced human error
    - Better quality control

Computers are a backbone for the forthcoming industrial revolution (Additive Manufacturing - 3D Printing)

- A conventional machine's slide is moved by an operator by turning the hand wheel.
- Accurate positioning is accomplished by the operator.




Finished part

Manual machining - feed, D.O.C.; V set by operator

Error, approximation, skill of operator

The same part can be made by NC or manual machining. The increased cost of NC can be offset by the decreased manufacturing time and improved quality

In N.C. ➔ Feed (f), D.O.C. (d); ➔ Cutting speed (V) ➔ Controlled through NC Part Program.

NC / CNC advantages:

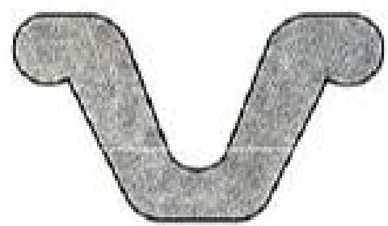
- BETTER QUALITY
- HIGHER PRODUCTIVITY
- LOWER REJECTION
- FACTORY OF FUTURE
- REDUCED INSPECTION

Selection of the process to manufacture the part

Which process to select and Why?

example

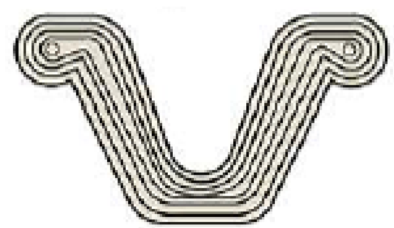
Cast part



Machined part

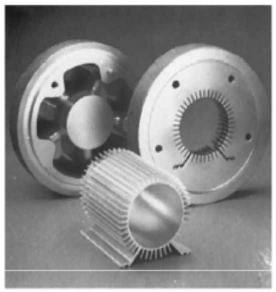
Grains in microstructure follow straight lines of machining tool

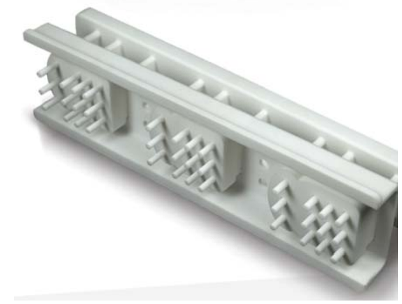
Forged part

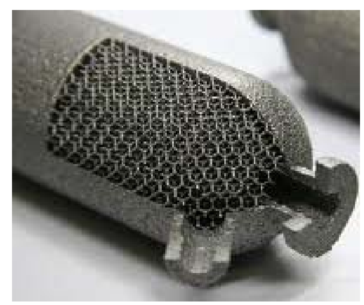


Grains in microstructure follow contours of the part

Select the suitable manufacturing processes for the following products







Questions

- 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
- Intricate shaped blind hole – e.g. square hole 15 mm×15 mm, depth 30 mm
- Difficult to machine material – e.g. Ti alloys, Inconel, Carbides
- Low Stress Grinding – Electrochemical Grinding is preferred as compared to conventional grinding
- Deep hole with small hole diameter – e.g. ϕ 1.5 mm hole with *h/d* = 20
- Machining of composites

Recap of the Lecture

- Manufacturing: Introduction
- Design for manufacturing
- Different materials in manufacturing
- Classification of manufacturing process
- Additive manufacturing, 3D printing
- Selection of the suitable manufacturing process

Next Lecture

Conventional material removal processes