FCME006
Basics of Mechanical Engineering
UNIT-III: Introduction to Manufacturing

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UNIT-III: Introduction to Manufacturing

- Classification and use of engineering materials, Basic principles and applications of methods of manufacturing such as casting, forming and joining; Working principles and applications of machining operations such as Turning, Thread cutting, Milling, Shaping, Grinding, etc., Use of automation in manufacturing.

WHAT IS MANUFACTURING?

- The word manufacture is derived from two Latin words, **manus** (hand) and **factus** (make); the combination means made by hand.
- The English word manufacture is several centuries old, and "**made by hand**" accurately described the manual methods used when the word was first coined.
- Most modern manufacturing is accomplished by automated and computer-controlled machinery

Introduction

- Making things has been an essential activity of human civilizations since before recorded history.

- For **technological** and **economic** reasons, manufacturing is important to the welfare of the developed and developing nations.

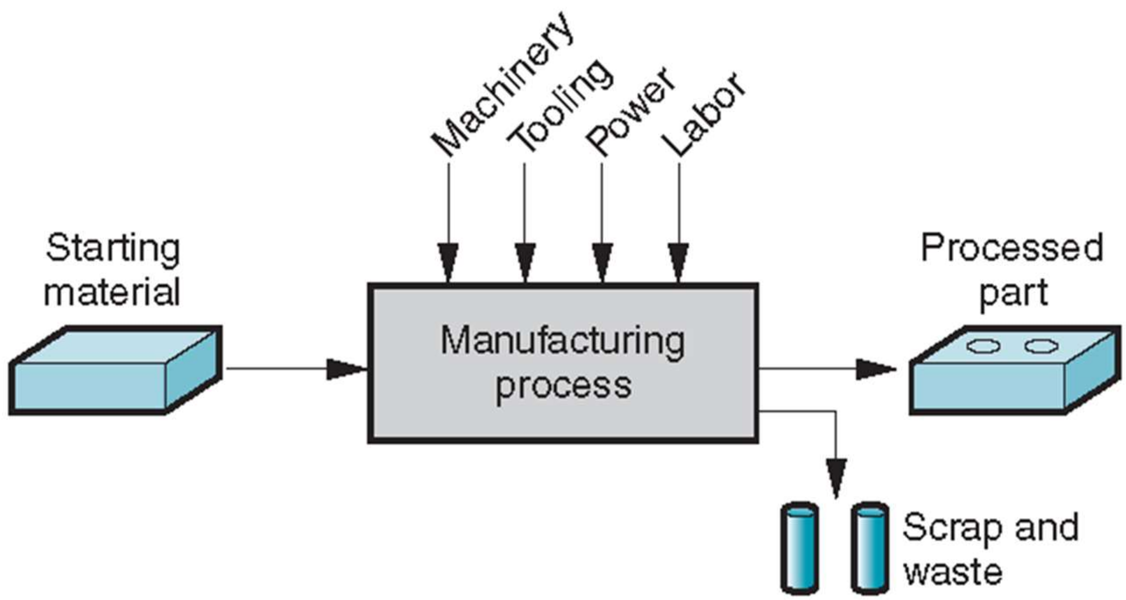
- Technology can be defined as the application of science to provide society and its members with those things that are needed or desired. Technology affects our daily lives, directly and indirectly, in many ways.

TABLE 1.1 Products representing various technologies, most of which affect nearly everyone.

Athletic shoes	Fax machine	One-piece molded plastic patio chair
Automatic teller machine	Flat-screen high-definition television	Optical scanner
Automatic dishwasher	Hand-held electronic calculator	Personal computer (PC)
Ballpoint pen	High density PC diskette	Photocopying machine
Cell phone	Home security system	Pull-tab beverage cans
Compact disc (CD)	Hybrid gas-electric automobile	Quartz crystal wrist watch
Compact disc player	Industrial robot	Self-propelled mulching lawnmower
Compact fluorescent light bulb	Ink-jet color printer	Supersonic aircraft
Contact lenses	Integrated circuit	Tennis racket of composite materials
Digital camera	Magnetic resonance imaging (MRI) machine for medical diagnosis	Video games
Digital video disc (DVD)	Microwave oven	Washing machine and dryer
Digital video disc player		

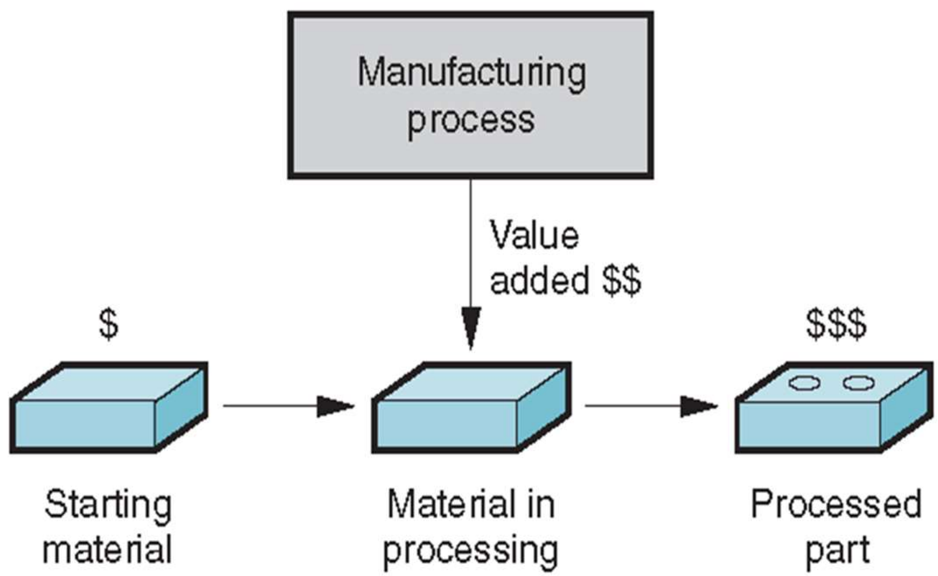
Manufacturing - Technological

- Application of physical and chemical processes to alter the geometry, properties, and/or appearance of a starting material to make parts or products



Manufacturing – Economic

- Transformation of materials into items of greater value by one or more processing and/or assembly operations



Manufacturing Industries

- Industry consists of enterprises and organizations that produce or supply goods and services

- Industries can be classified as:

1. **Primary industries** - cultivate and exploit natural resources, e.g., agriculture, mining

2. **Secondary industries** - take the outputs of primary industries and convert them into consumer and capital goods

3. **Tertiary industries** - service sector

Manufacturing Industries - Continued

- Secondary industries include manufacturing, construction, and electric power generation

- For our purposes, manufacturing means production of hardware
  - Nuts and bolts, forgings, cars, airplanes, digital computers, plastic parts, and ceramic products

TABLE 1.2 Specific industries in the primary, secondary, and tertiary categories.

Primary	Secondary		Tertiary (Service)	
Agriculture	Aerospace	Food processing	Banking	Insurance
Forestry	Apparel	Glass, ceramics	Communications	Legal
Fishing	Automotive	Heavy machinery	Education	Real estate
Livestock	Basic metals	Paper	Entertainment	Repair and maintenance
Quarries	Beverages	Petroleum refining	Financial services	
Mining	Building materials	Pharmaceuticals	Government	Restaurant
Petroleum	Chemicals	Plastics (shaping)	Health and medical	Retail trade
	Computers	Power utilities		Tourism
	Construction	Publishing	Hotel	Transportation
	Consumer appliances	Textiles	Information	Wholesale trade
		Tire and rubber		
	Electronics	Wood and furniture		
	Equipment			
	Fabricated metals			

Manufactured Products

- Final products divide into two major classes:

1. **Consumer goods** - products purchased directly by consumers
   - Cars, clothes, TVs, tennis rackets

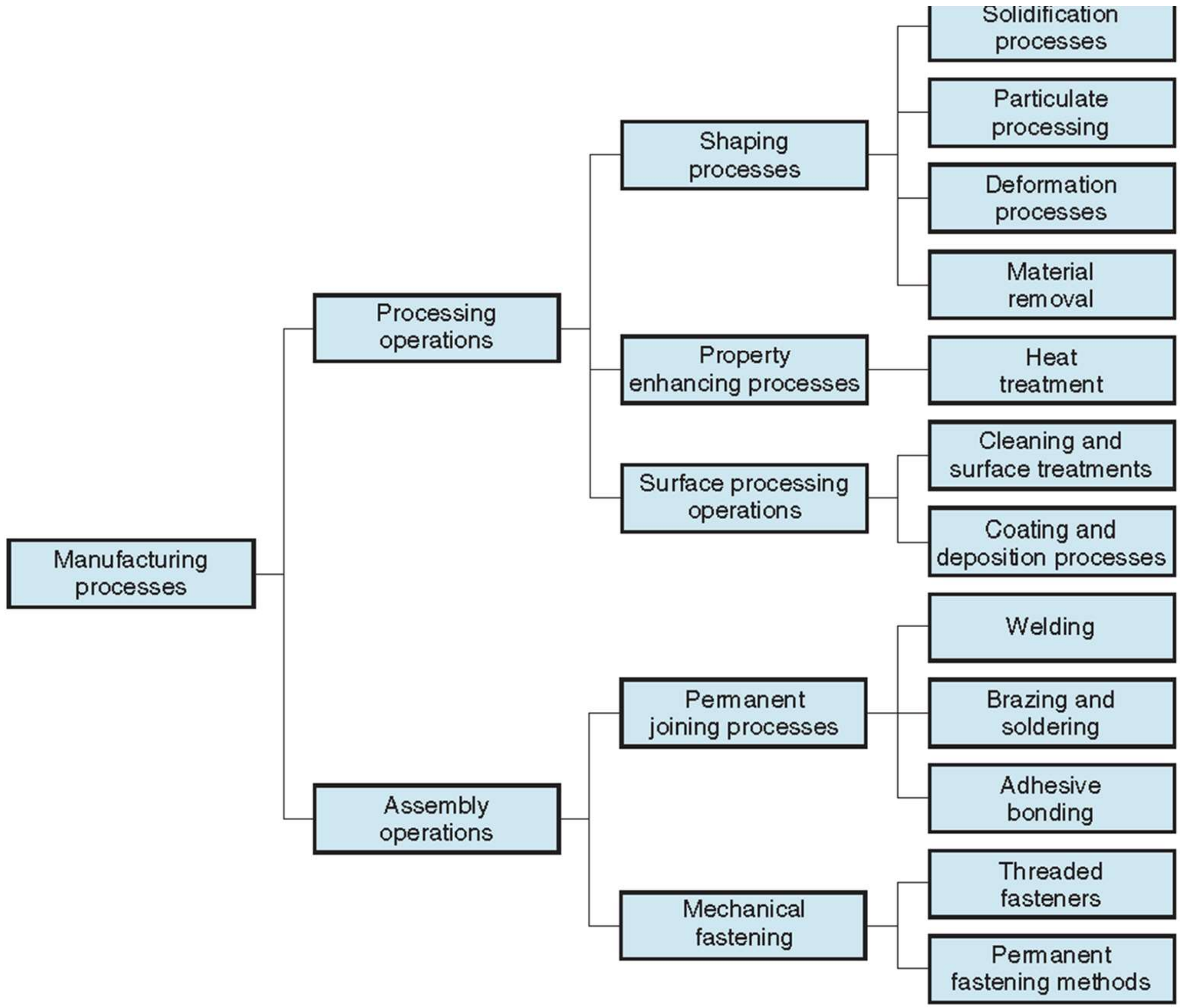
2. **Capital goods** - those purchased by companies to produce goods and/or provide services
   - Aircraft, computers, communication equipment, medical apparatus, trucks, machine tools, construction equipment

Manufacturing Processes

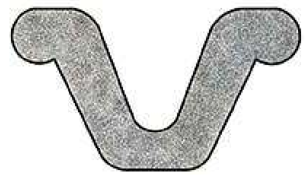
Two basic types:

1. **Processing operations** - transform a work material from one state of completion to a more advanced state
   - Operations that change the geometry, properties, or appearance of the starting material

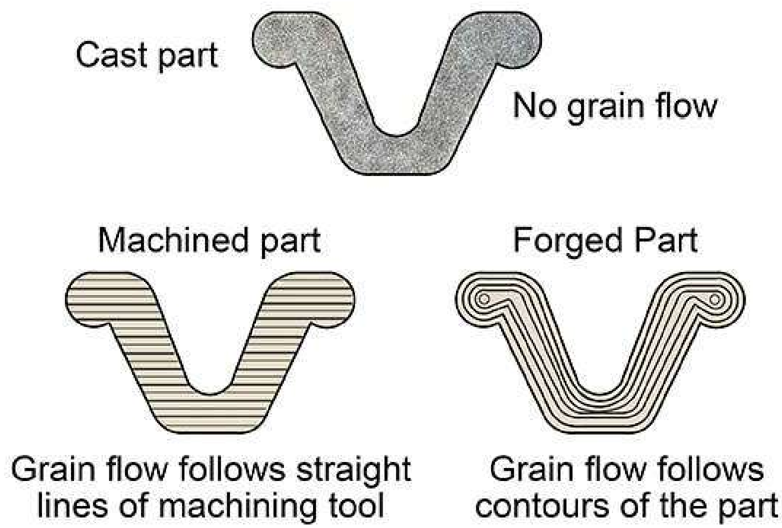
2. **Assembly operations** - join two or more components to create a new entity


Manufacturing processes
Processing operations
Assembly operations
Shaping processes
Property enhancing processes
Surface processing operations
Permanent joining processes
Mechanical fastening
Solidification processes
Particulate processing
Deformation processes
Material removal
Heat treatment
Cleaning and surface treatments
Coating and deposition processes
Welding
Brazing and soldering
Adhesive bonding
Threaded fasteners
Permanent fastening methods

Question



Which Process to Select and Why?



www.wonkeedonkeetools.co.uk

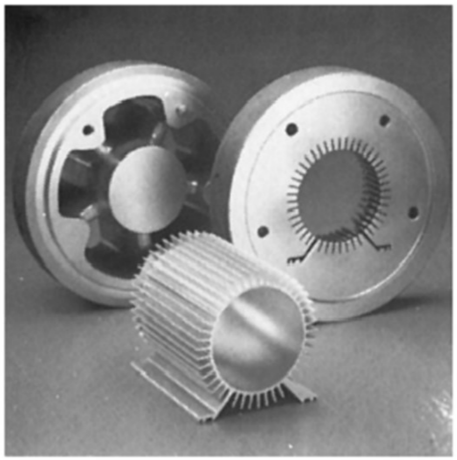
Questions

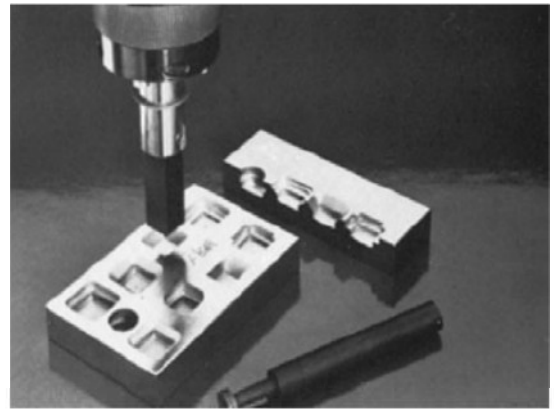
- Need to machine newly developed metals and non-metals with special properties that make them difficult or impossible to machine by conventional methods
- Need for unusual and/or complex part geometries that cannot easily be accomplished by conventional machining
- Need to avoid surface damage that often accompanies conventional machining

Example

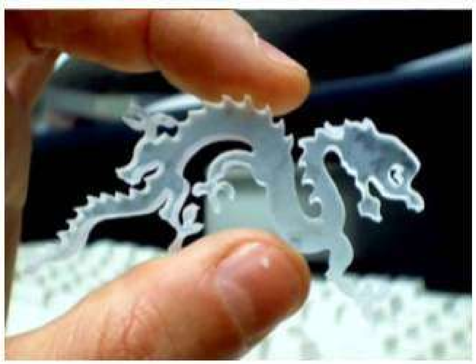
- Intricate shaped blind hole – e.g. square hole of 15 mm x 15 mm with a depth of 30 mm
- Difficult to machine material – e.g. same example as above in Inconel, Ti- alloys or carbides.
- Low Stress Grinding – Electrochemical Grinding is preferred as compared to conventional grinding
- Deep hole with small hole diameter – e.g. φ 1.5 mm hole with $l/d = 20$
- Machining of composites.

Questions





Stepped cavities



Bullet Proof Glass Part

Ceramic Part

Source: http://www.waterjets.org/

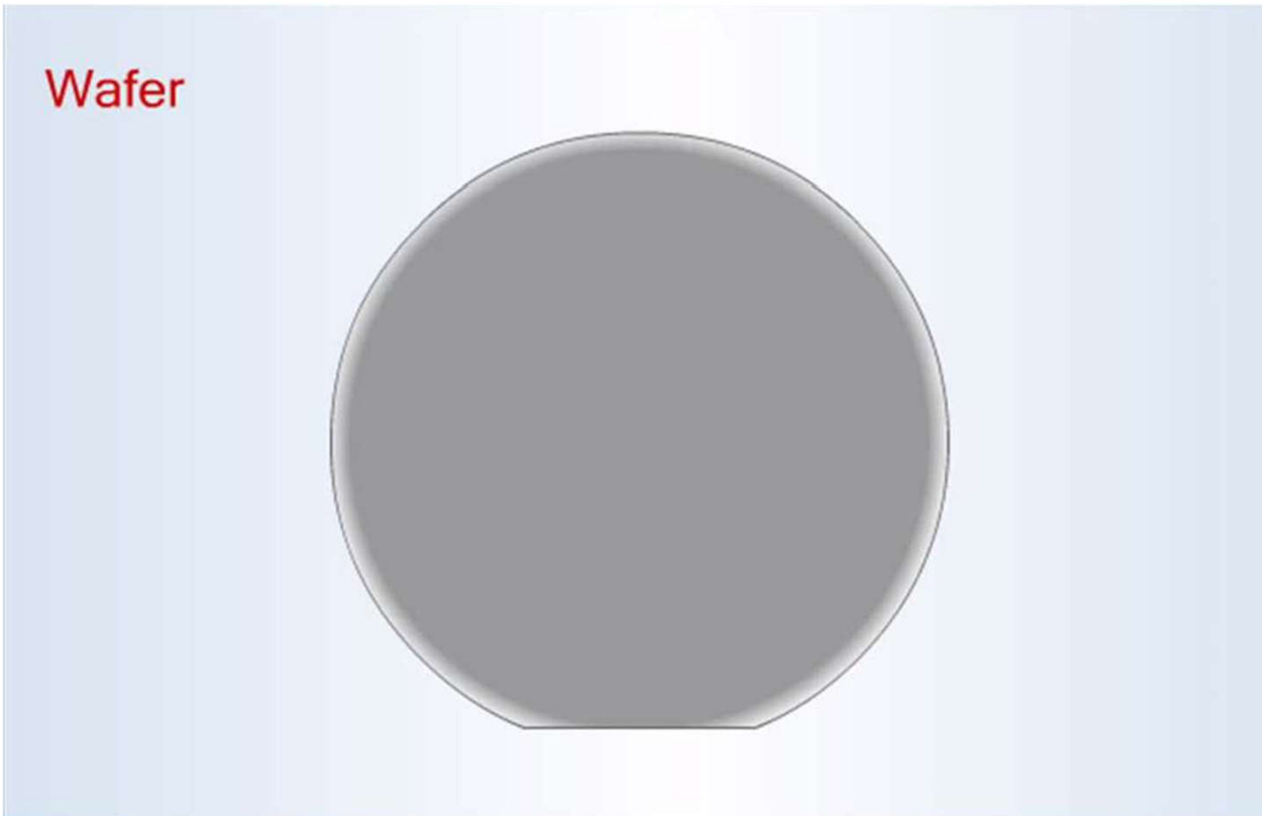
Questions

cake

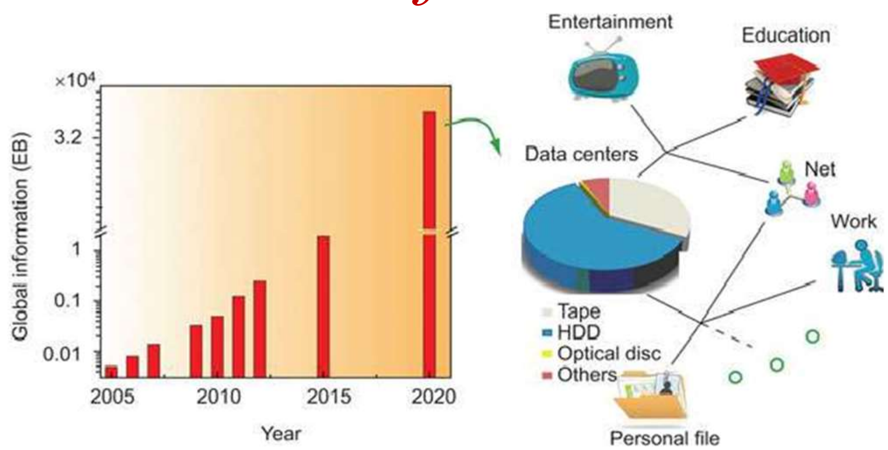
fish

PWB (printed wire board)

Microfabrication



Miniaturization: Information Storage



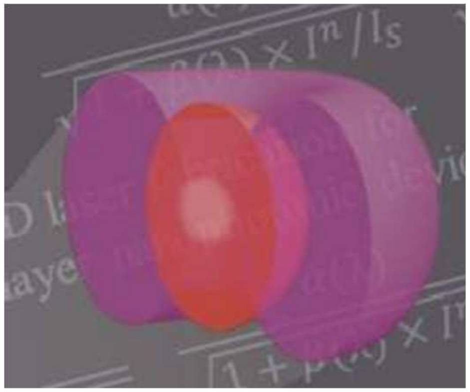
Data recording on a disc

- **The information is transformed to strings of binary digits (0s and 1s, also called bits).**
- **Each bit is then laser "burned" into the disc, using a single beam of light, in the form of dots.**
- **The storage capacity of optical discs is mainly limited by the physical dimensions of the dots.**

Fgure Source: International Data Corporation (IDC)

Miniaturization: Information Storage

How far can we reduce the size of the dots?



Abbe's Limit:

If a light beam is focused through a lens, the diameter of the resulting spot of light can't be smaller than half its wavelength.

Way to get around the problem

❖**The first beam (red, in the figure) has a round shape, and is used to write data.**

❖**Then, place a doughnut-shaped laser (purple, in the figure) around the initial laser in order to limit the abilities of the first beam. This effectively made the standard laser's diameter smaller, and it could then write smaller bits.**

Source: http://theconversation.com/more-data-storage-heres-how-to-fit-1-000-terabytes-on-a-dvd-15306

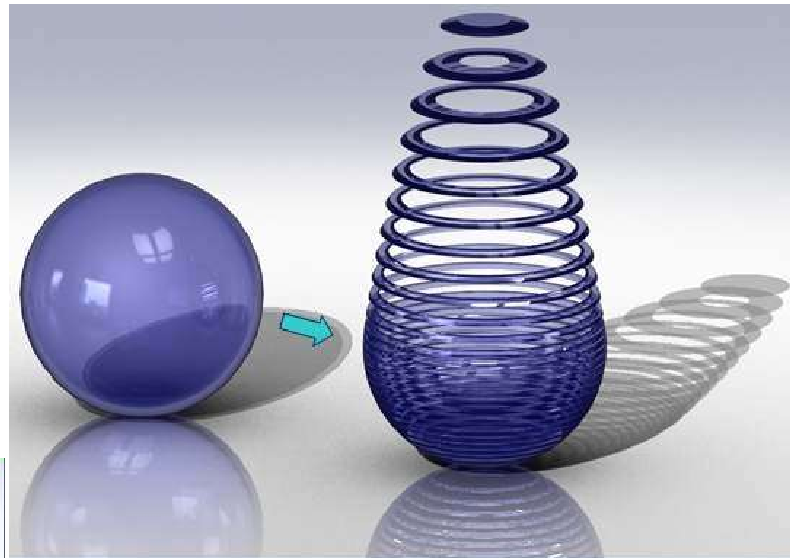
Layered/Additive Manufacturing

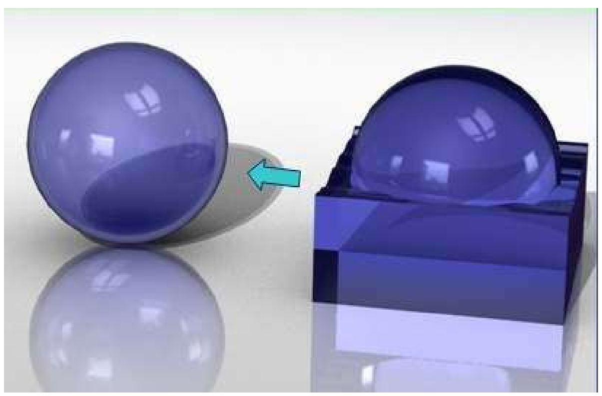
Additive Manufacturing (AM) refers to a process by which digital 3D design data is used to build up a component in layers by depositing material.
(from the International Committee F42 for Additive Manufacturing Technologies, ASTM)..

What You See Is What You Build (WYSIWYB) Process

Additive vs Subtractive Manufacturing

- Part Complexity;
- Material;
- Speed;
- Part Quantity;
- Cost.





Additive vs Subtractive Manufacturing

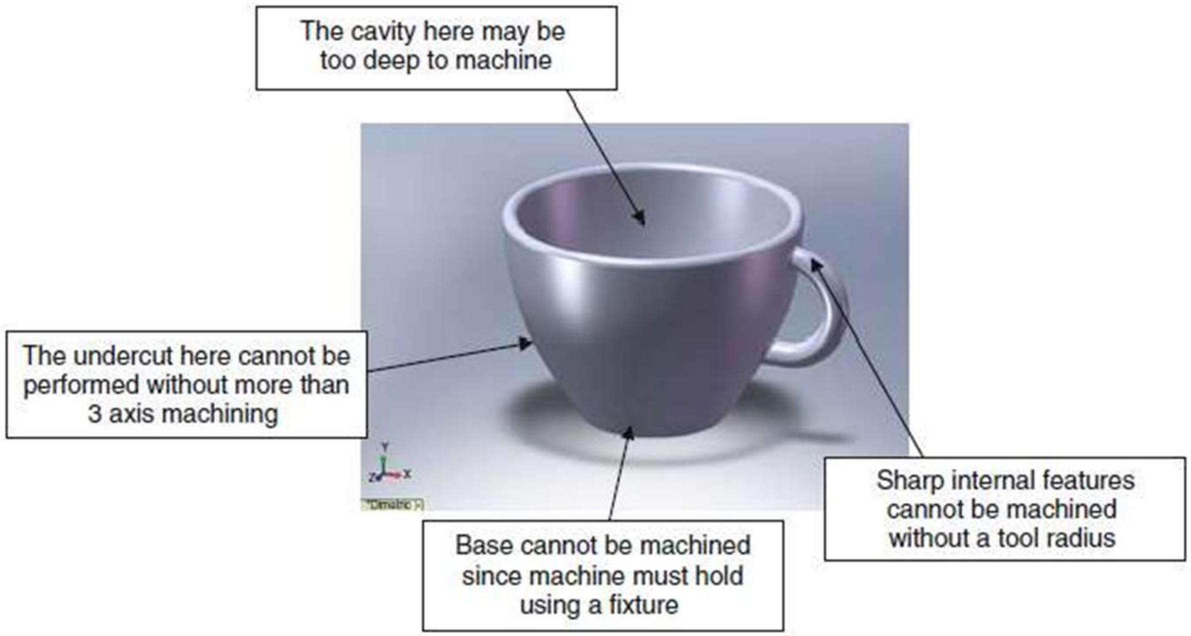
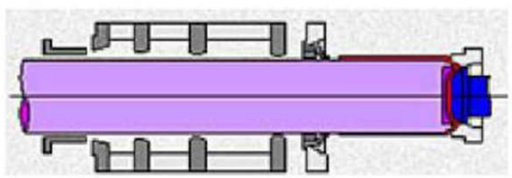


Figure: Features that represent problems using CNC machining.

Source: Gibson, Additive Manufacturing

Additive vs Forming Manufacturing

- Expensive tools are typically required for the forming processes.

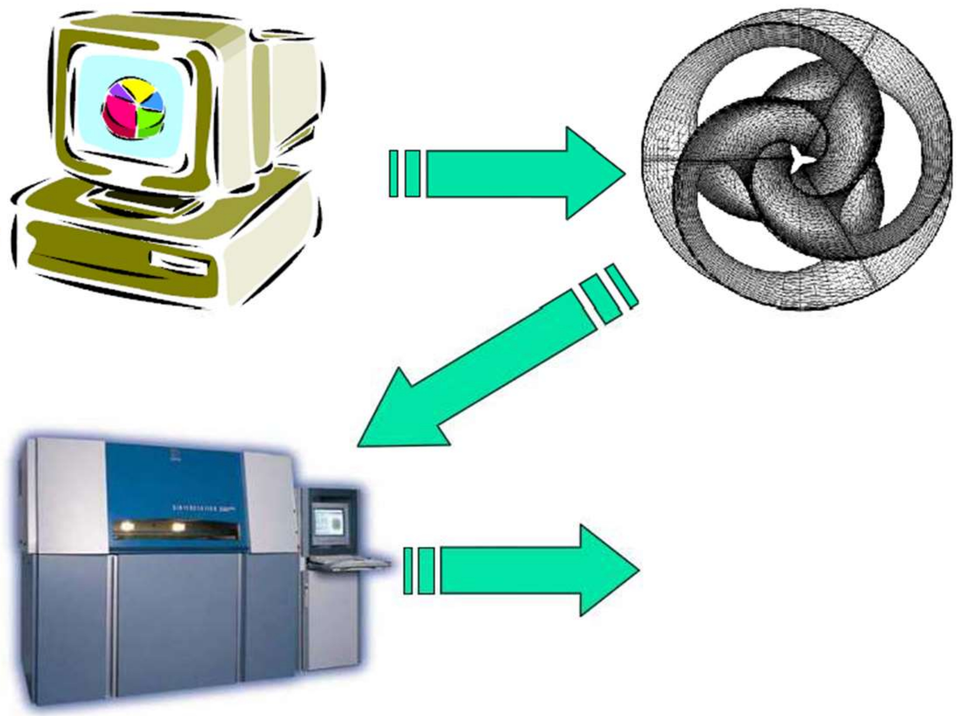


Dies for Metal Cans

Plastic Stool

Advantages of Additive Manufacturing

- Flexibility: directly fabricate parts from CAD models
- Less waste: add material, light weight structure, green manufacturing
- Reduced time to market, shorten supply chain
- Innovation: complex part and multi-functional part



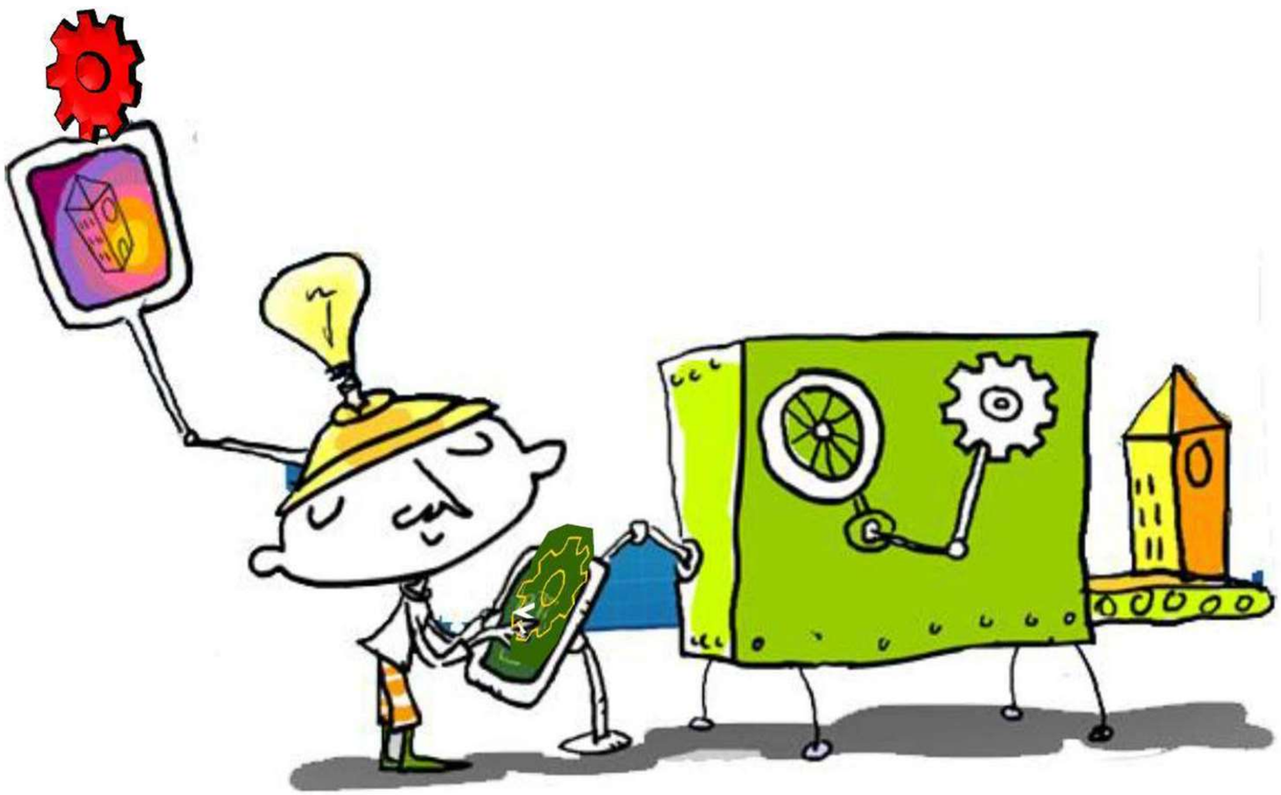

Wright Brothers
First flight in 1903

Principle 1: Complexity is Free

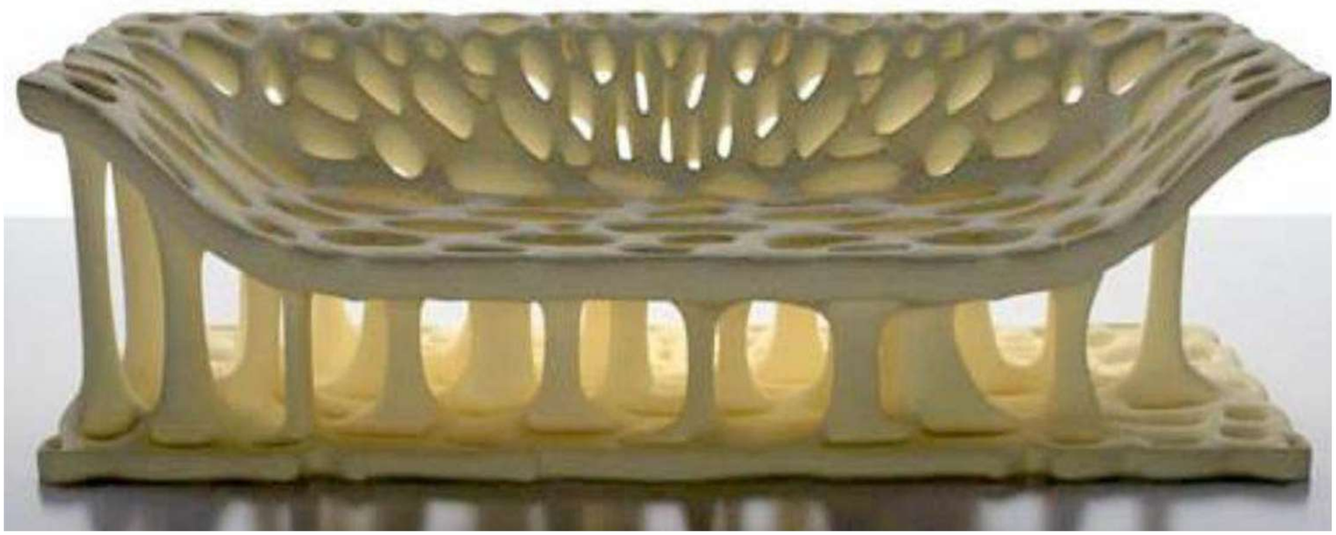
Principle 2: Variety is Free

Principle 3: No Assembly Required

Principle 4: Zero Lead Time

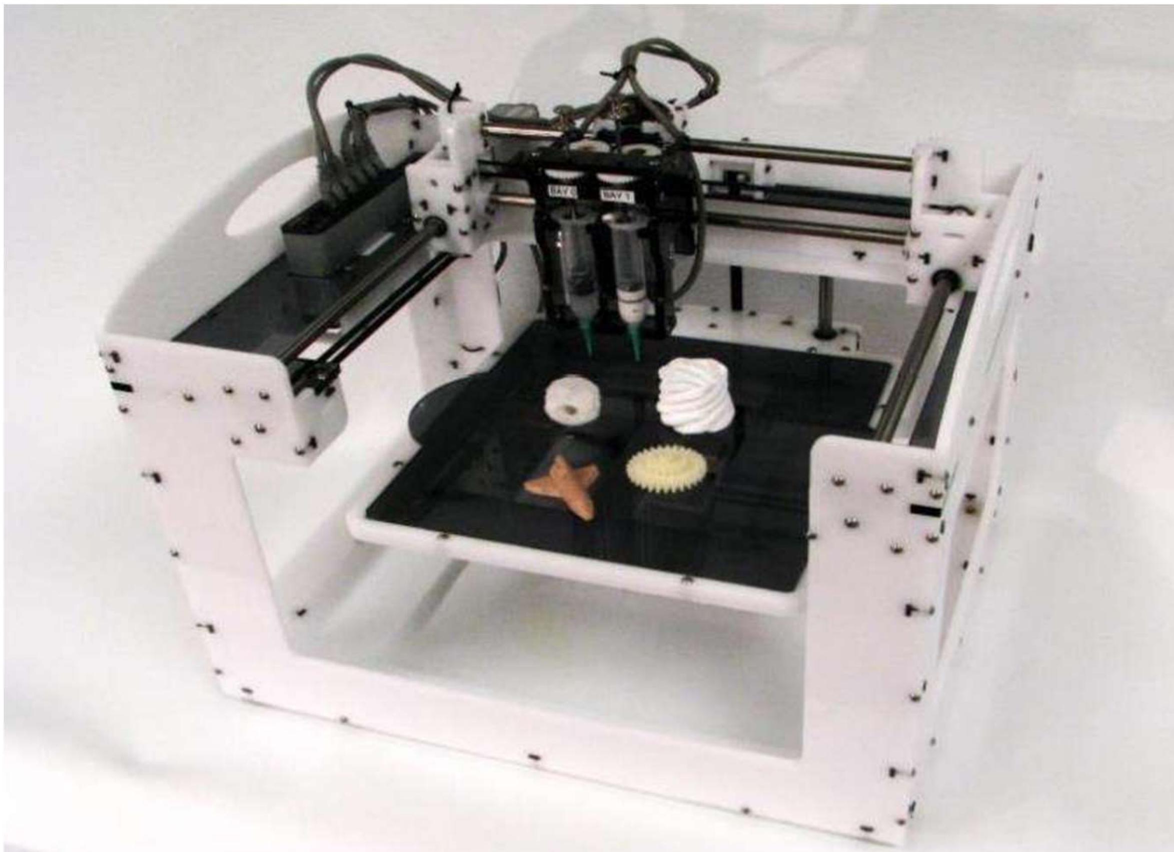


Principle 5: Zero Constraints

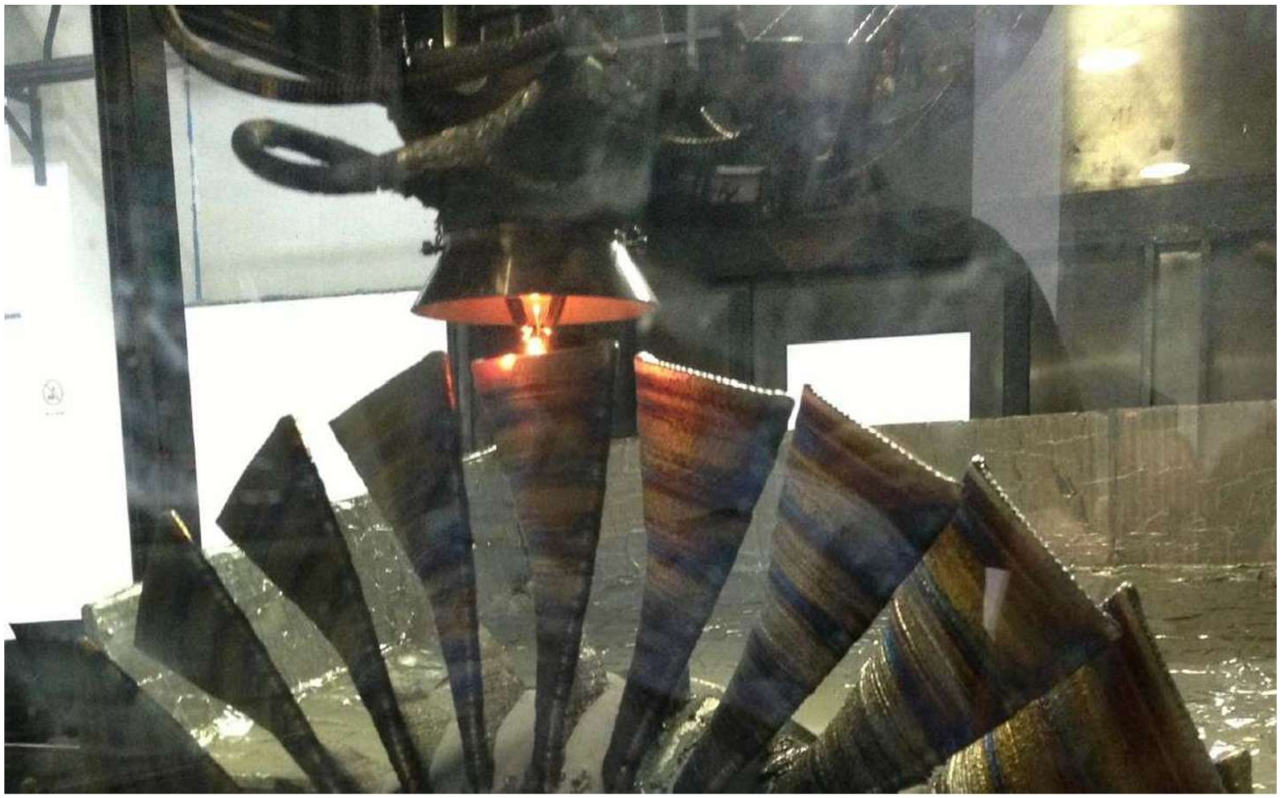


Principle 6: Zero Skill Manufacturing

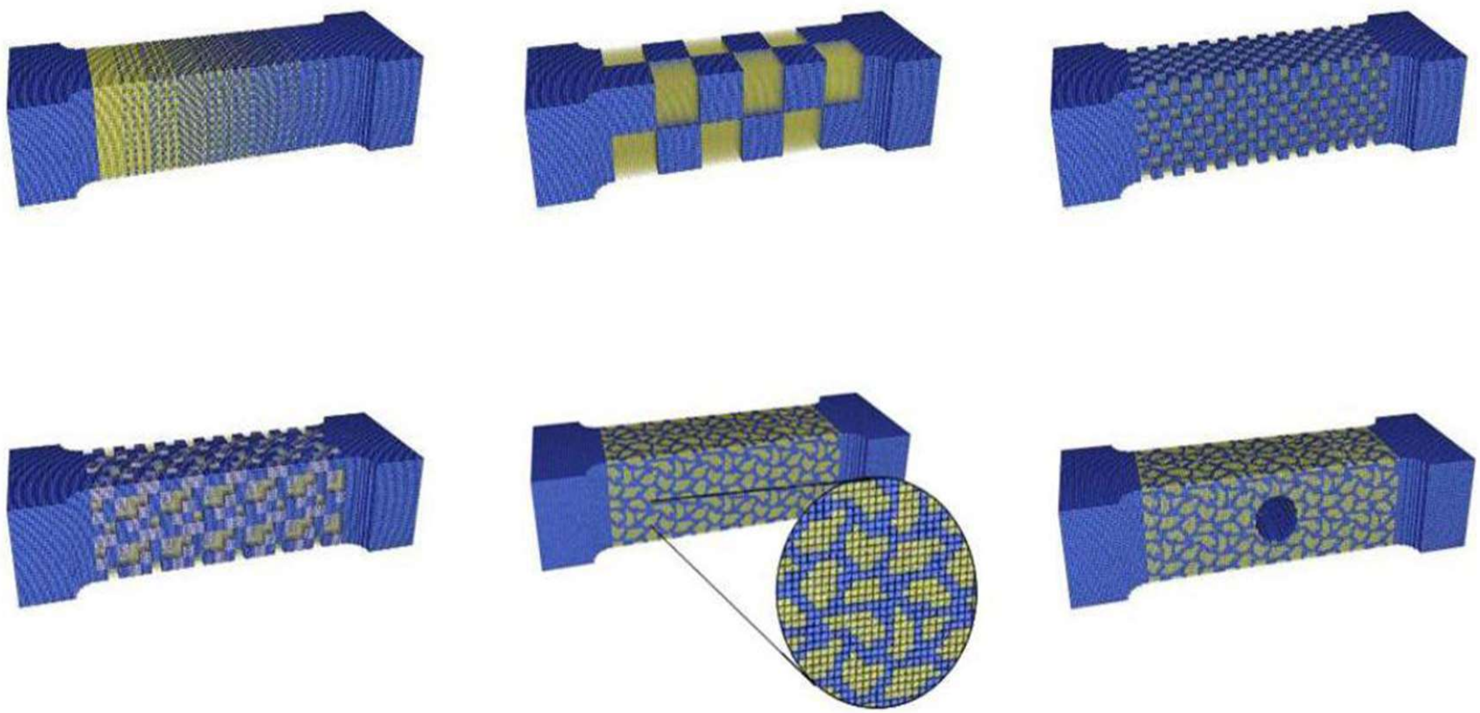
Principle 7: Compact & Portable Manufacturing



Principle 8: Less Waste By-product



Principle 9: Infinite Shades of Materials



Principle 10: Precise Replication

Source
Google images

Current and Potential industries for Additive Manufacturing

Benefits

AM benefits: Weight reduction

TRADITIONAL DESIGN

Source: SAVING project

- > A conventional steel buckle weights 155 g[1)]
- > Weight should be reduced on a like-for-like basis within the SAVING project
- > Project partners are Plunkett Associates, Crucible Industrial Design, EOS, 3T PRD, Simpleware, Delcam, University of Exeter

AM OPTIMIZED DESIGN

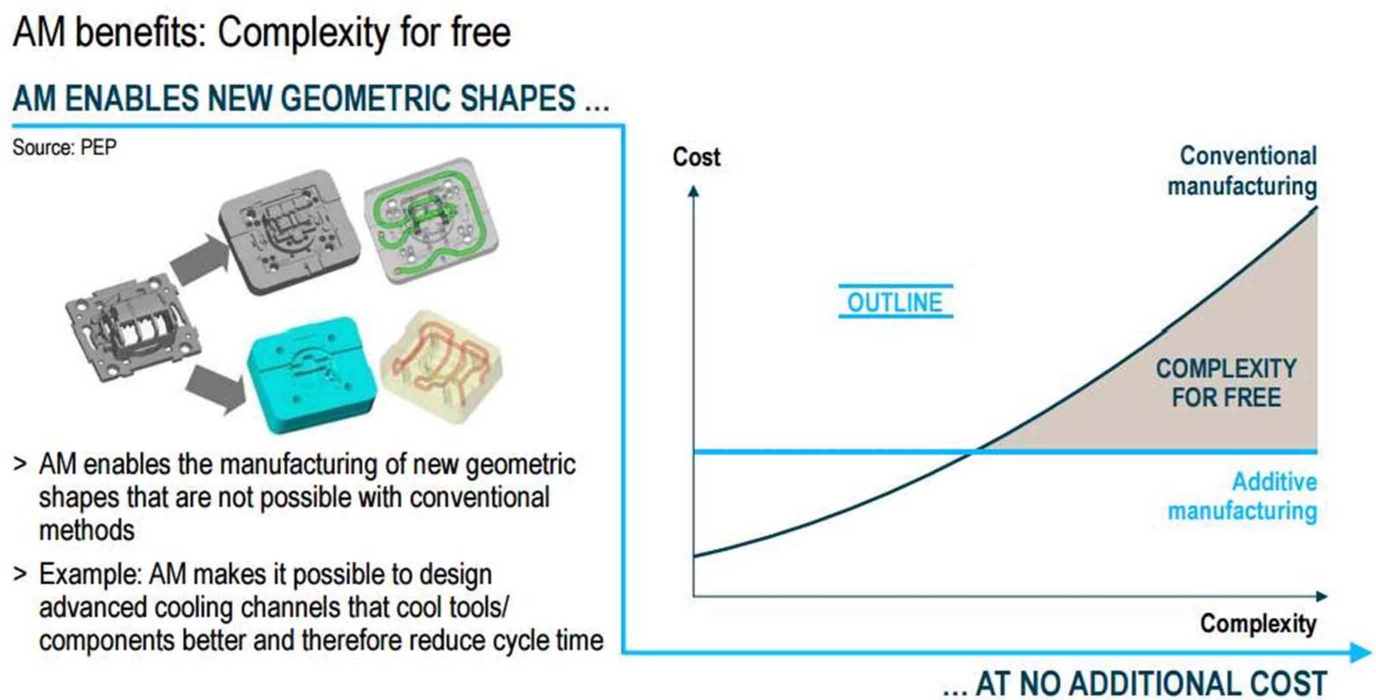
Source: SAVING project

- > Titanium buckle designed with AM weighs 70 g – reduction of 55%
- > For an Airbus 380 with all economy seating (853 seats), this would mean a reduction of 72.5 kg
- > Over the airplane's lifetime, 3.3 million liters of fuel or approx. EUR 2 m could be saved, assuming a saving of 45,000 liters per kg and airplane lifetime

1) 120 g when made of aluminum

Source: SAVING project/Crucible Industrial Design Ltd.; Roland Berger

Benefits



Source: Roland Berger

Benefits

AM for customized medical products

DENTAL CROWNS/BRIDGES

Source: EOS

- **AM holds a large share of the dental crowns and bridges market –** Geometry is scanned and processed via CAD/CAM. More than 30 million crowns, copings and bridges have already been made on AM machines over the last 6 years
- **Increasing market share –** Experts estimate that more than 10,000 copings are produced every day using AM
- **Faster production –** One AM machine produces up to 450 crowns per day, while a dental technician can make around 40

IMPLANTS

Source: EOS

- **AM offers advantages with regard to manufacturing time, geometric fit and materials –** Example of a skull implant with modified surface structure
- **Improved fit via AM –** Based on 3D scans of the skull, the resulting implant fits perfectly into the skull cap, leads to faster recovery and reduces operation time

Additive manufacturing will replace conventional manufacturing methods for customized products

Source: Roland Berger

Future: Home Manufacturing

Case Studies

CASE STUDY

ROLLS-ROYCE

Rolls-Royce is considering embarking on the additive manufacture of entire components because of the benefits of faster production and reduced costs that it offers. Says Rolls-Royce's Neil Mantle: "At the launch of an engine programme we start to consider forgings, and AM gives us a great opportunity here because conventional methods of manufacture can take 40, 50 or even 60 weeks, while a component using AM will take one month." Likewise, he praised the improved buy-to-fly ratio on materials: "Sometimes we machine away 90% of the materials to create the final component, but with AM that figure is much reduced." Neil Mantle added that while AM offers distinct advantages, investing in AM machines will require Rolls-Royce to feel confident of their economic viability and that the processes will be as robust and reliable as traditional methods.

CASE STUDY

VIRGIN UPPER CLASS MONITOR ARM

In a Technology Strategy Board (TSB) funded project for Virgin Atlantic, the arm holding the TV monitor in the airline's Upper Class seats was redesigned for AM. Latticing reduced the arm's weight by 50%, saving 0.5 kilograms for every unit, in turn saving $45,000 worth of fuel across the 30-year lifetime of the aircraft. "You can make an economic case for AM on that one component," said Dr Chris Tuck, Associate Professor of Additive Manufacturing and 3D Printing Research Group at the University of Nottingham.

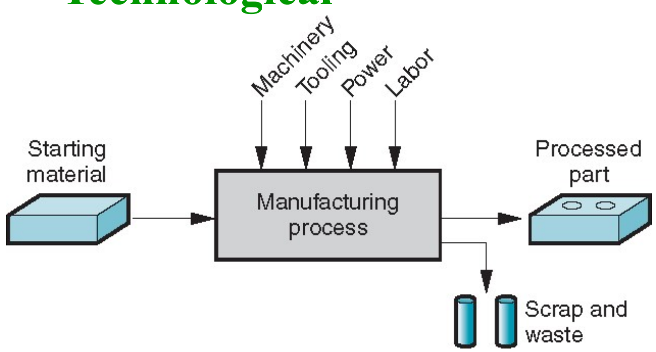
Source: Royal Academy of Engin

Manufacturing

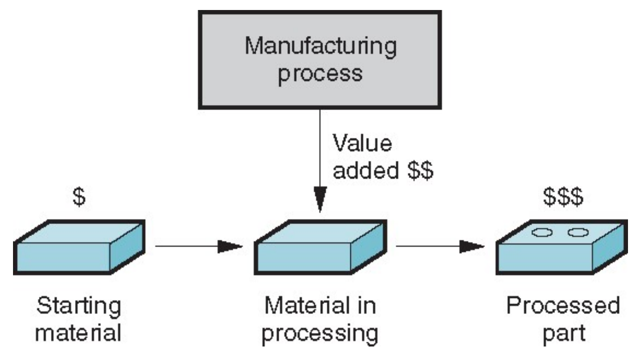
Derived from two latin word *manus* (hand) and *factus* (make); the combination means "made by hand"

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 .

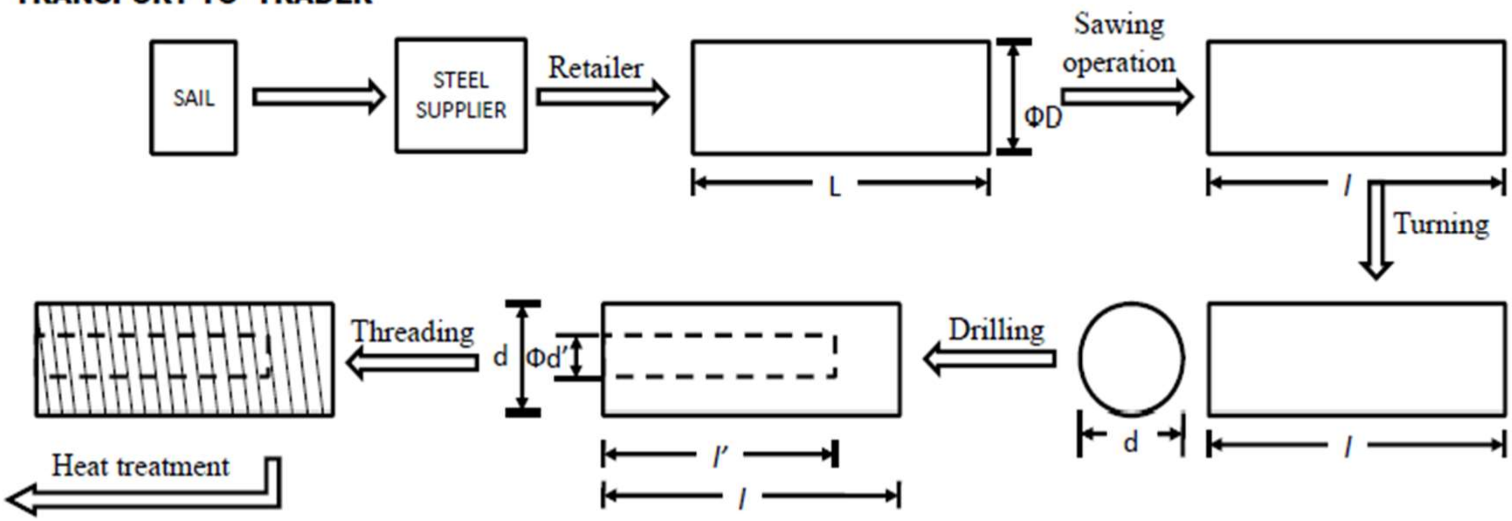
- **Material issues:**
- ***Type of material. Stiffness (deflection/ force) & strength (yield stress: stress to cause permanent deformation. If it is too strong, a lot of force will be required but if it is too weak, it may not work in holding the papers etc).***

- **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



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**

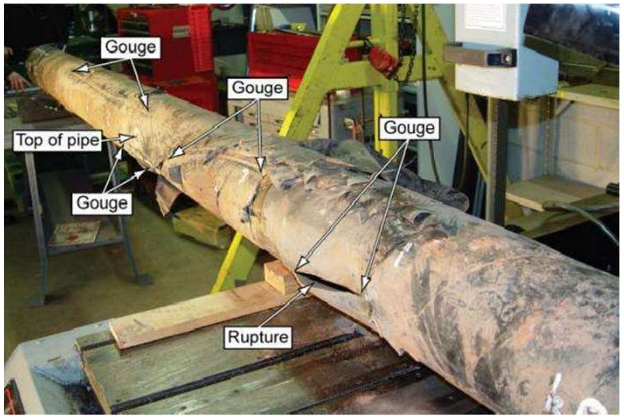
Final product: Weight 3 kg, Cost – Rs 500/. RAW MATERIAL COST Rs. 60/ PER Kg

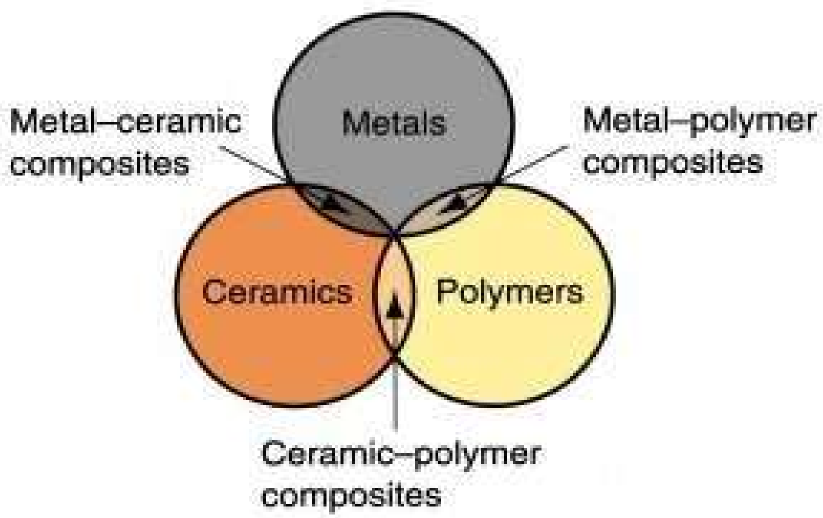
Manufacturing contd.

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

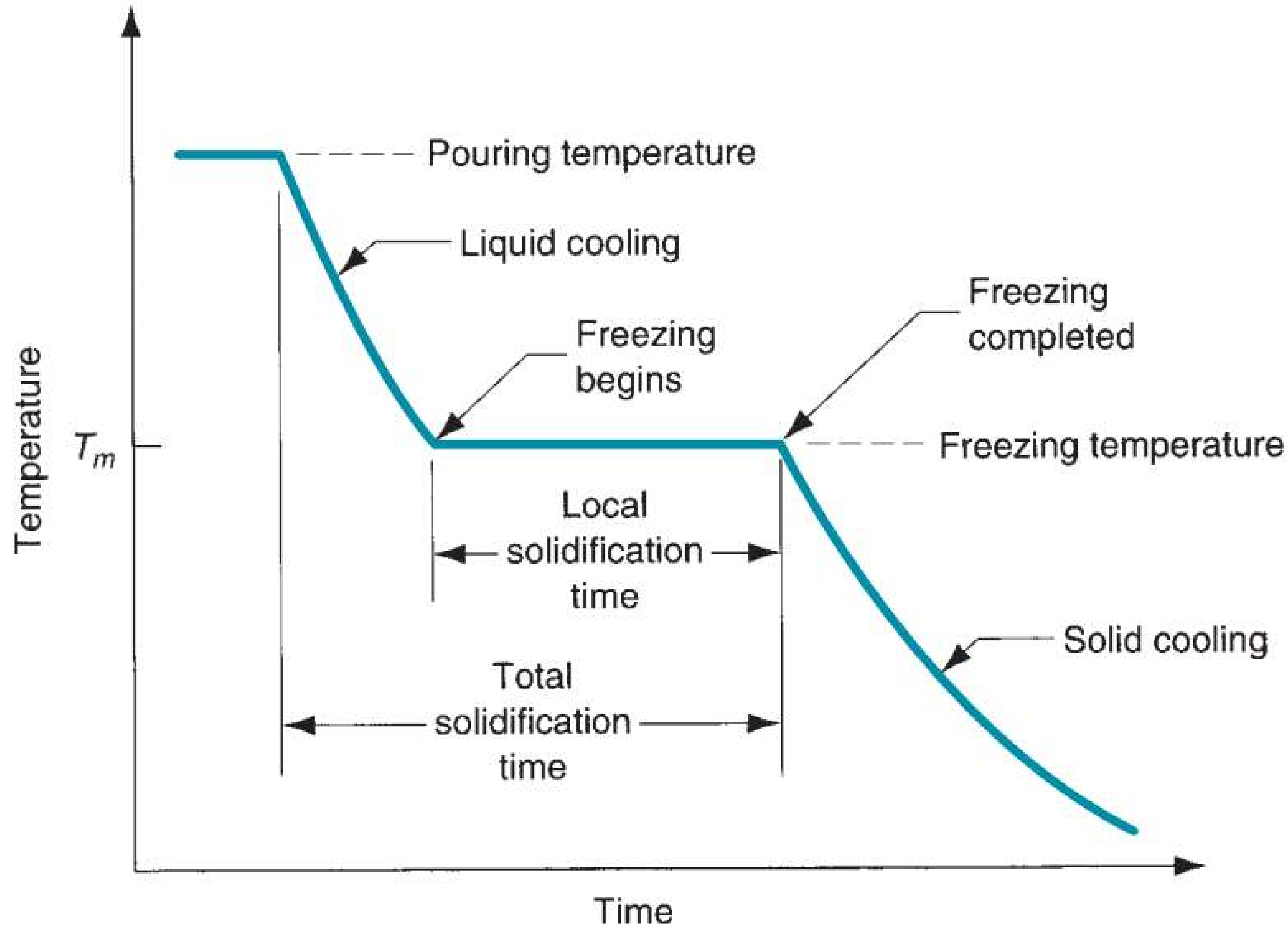
- Usually *alloys*, which are composed of two or more elements, at least one of which is metallic. Two basic groups:
  1. **Ferrous metals** - based on iron, comprises about 75% of metal tonnage in the world:
     - Steel and cast iron
  2. **Nonferrous metals** - all other metallic elements and their alloys:
     - Aluminum, copper, nickel, silver, tin, etc.

1. Metals

Charging a basic oxygen furnace in steelmaking: molten pig iron is poured. Temperatures are around 1650C (3000F).

Source: 2010 John Wiley & Sons, Inc. M P Groover, ***Fundamentals of Modern Manufacturing*** 4/e

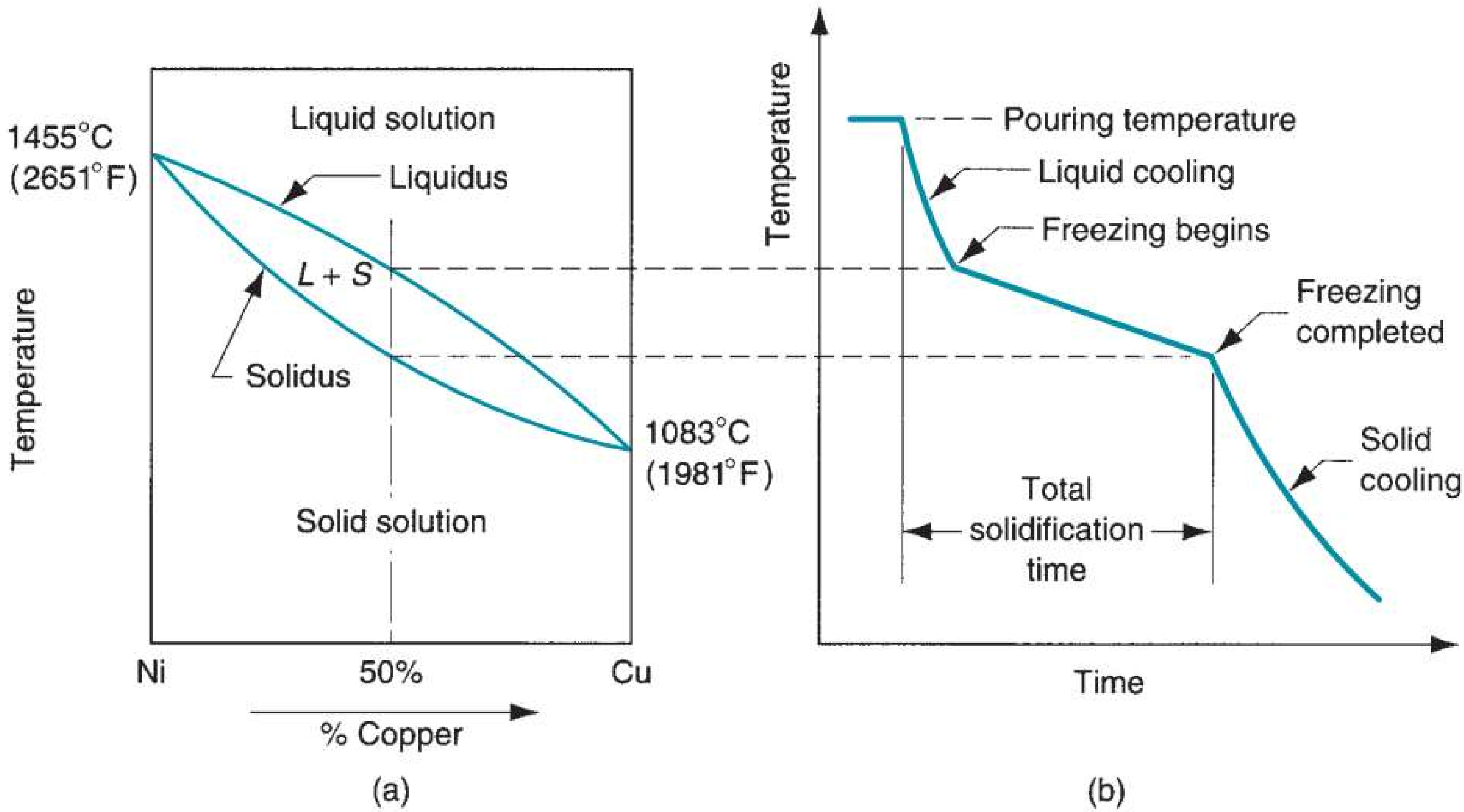
1. Metals



Cooling curve for a pure metal during casting.

Source: 2010 John Wiley & Sons, Inc. M P Groover, ***Fundamentals of Modern Manufacturing*** 4/e

1. Metals



(a) Phase diagram for a copper– nickel alloy system and (b) associated cooling curve for a 50%Ni–50%Cu composition during casting.

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

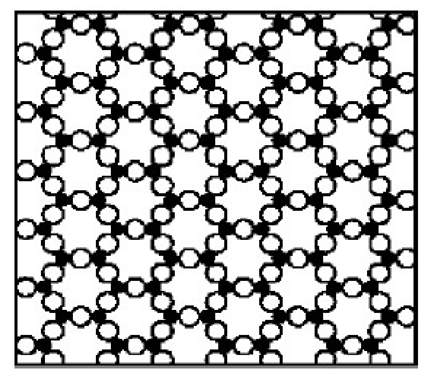
Examples

- 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_3Al)

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 (Al_2O_3)
  2. Glasses – mostly based on silica (SiO_2)



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 (Al_2O_3) and Silica (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

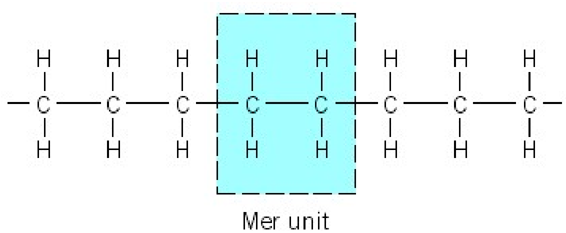
Examples

- Simple oxides (SiO_2, Al_2O_3, Fe_2O_3, MgO)
- Mixed-metal oxides ($SrTiO_3$, $MgAl_2O_4$, $YBa_2Cu_3O_{7-x}$)
- Nitrides (Si_3N_4, AlN, GaN, BN, and TiN, which are used for hard coatings)

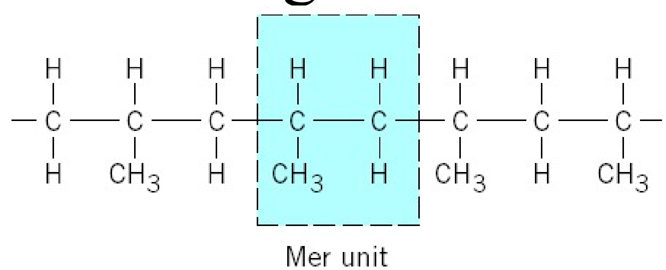
3. Polymers

- 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 C_2H_4)



Polypropylene: (the *mer* unit is C_3H_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 intefaces), 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

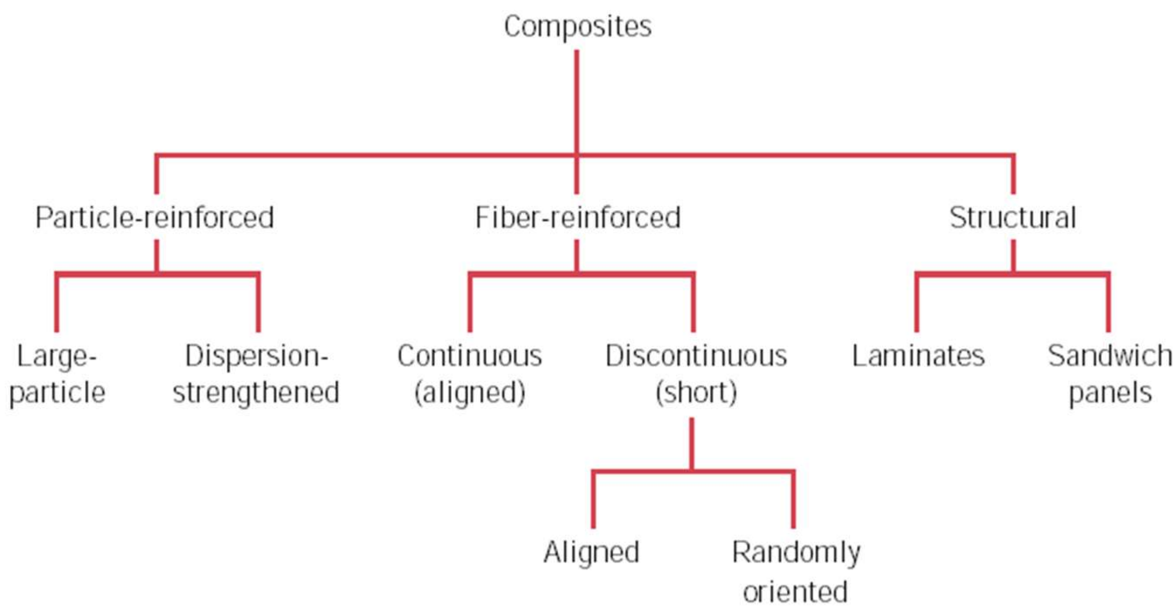
Matrix phase : The continuous phase Purpose is to

- 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



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

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

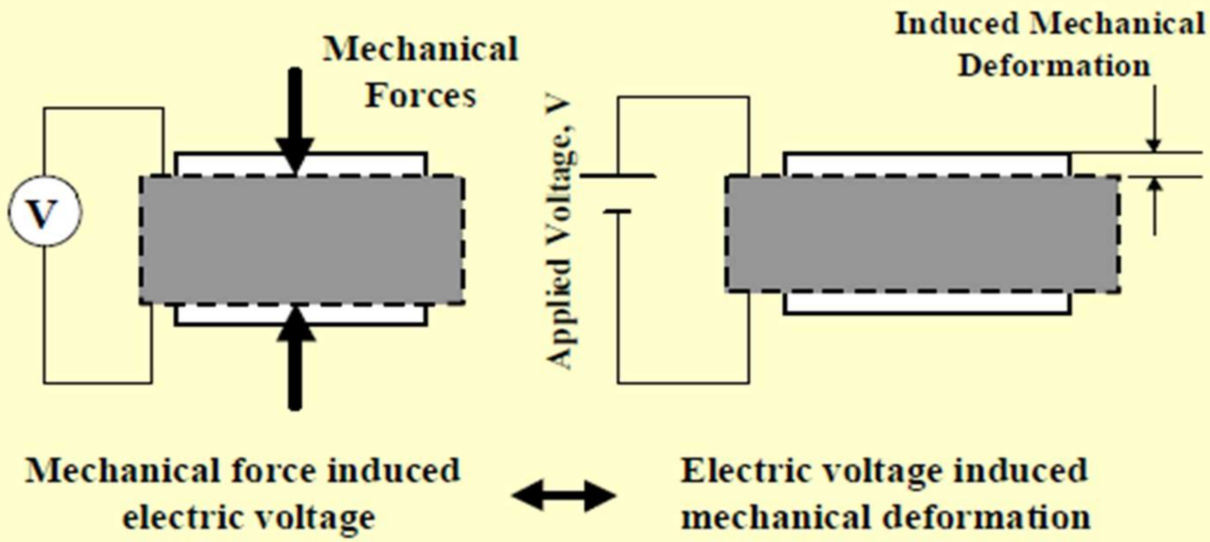
APPLICATIONS:

Can be used

- To generate motion and/or force in temperature- sensitive actuators
- Eyeglass frames, connectors, clamps and fasteners

Piezoelectric Materials

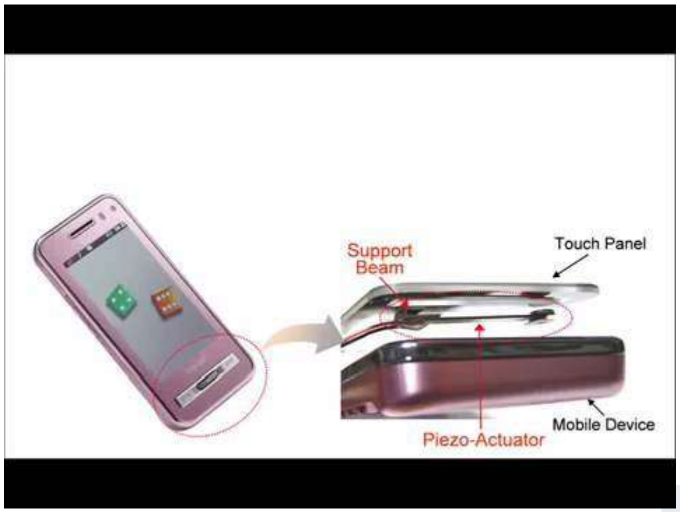
- Piezoelectric crystals are solid ceramic compounds that produce piezoelectric effects:



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

- Synthesized crystals are: Rochelle salt, barium titanate and lead zirconate.

Piezoelectricity



Biomaterials

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

Metals	Ceramics	Polymers
316L stainless steel Co-Cr Alloys Titanium Ti6Al4V	Alumina Zirconia Carbon Hydroxyapatite	Ultra high molecular weight polyethylene Polyurethane

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

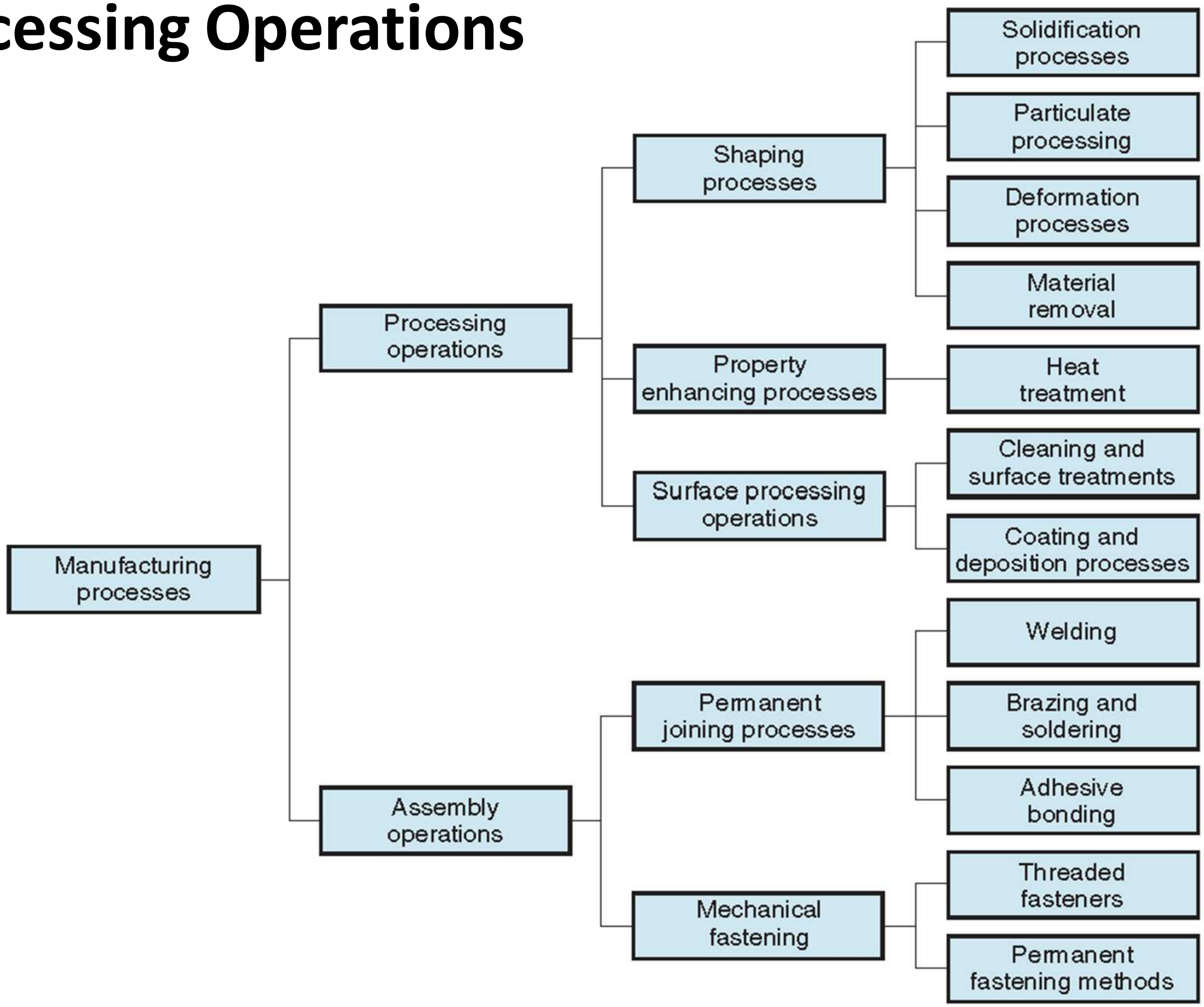
Cardiovascular Applications

- 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.

Processing Operations



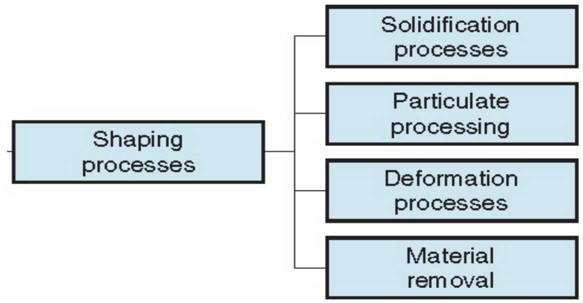
Processing Operations

Alters a material's shape, physical properties, or appearance in order to add value

- Three categories of processing operations:

1. **Shaping operations -** alter the geometry of the starting work material
2. **Property-enhancing operations -** improve physical properties without changing shape
3. **Surface processing operations -** clean, treat, coat, or deposit material on surface of work

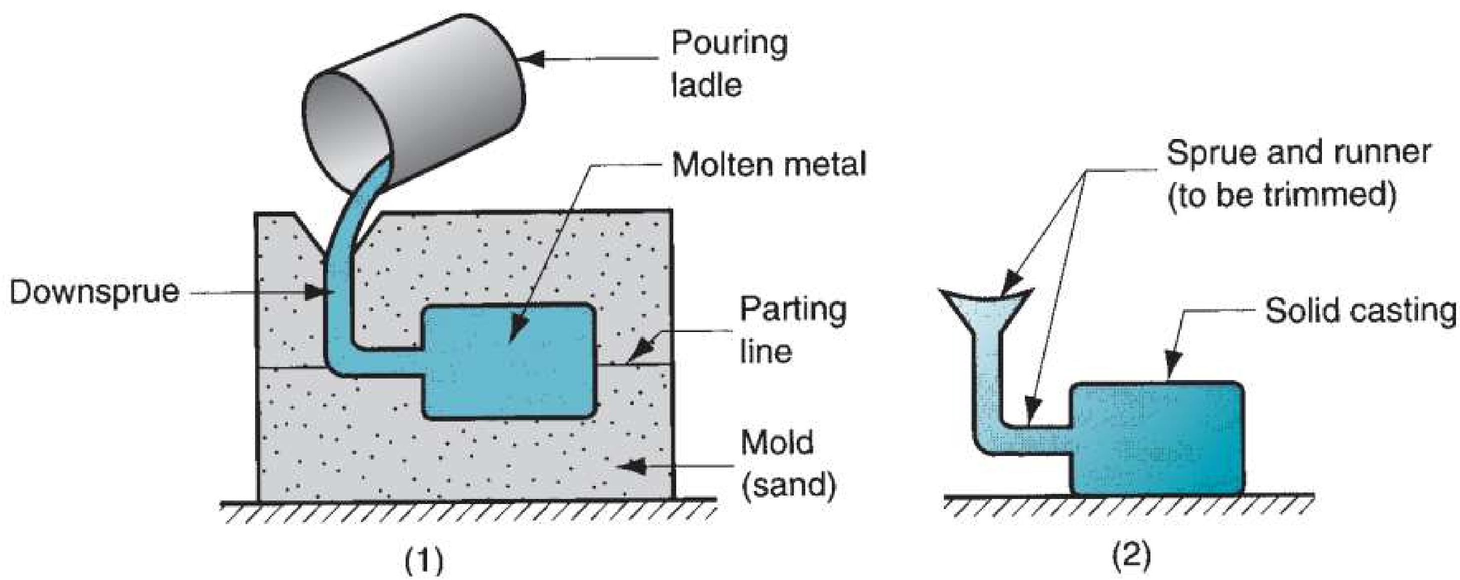
Shaping Processes



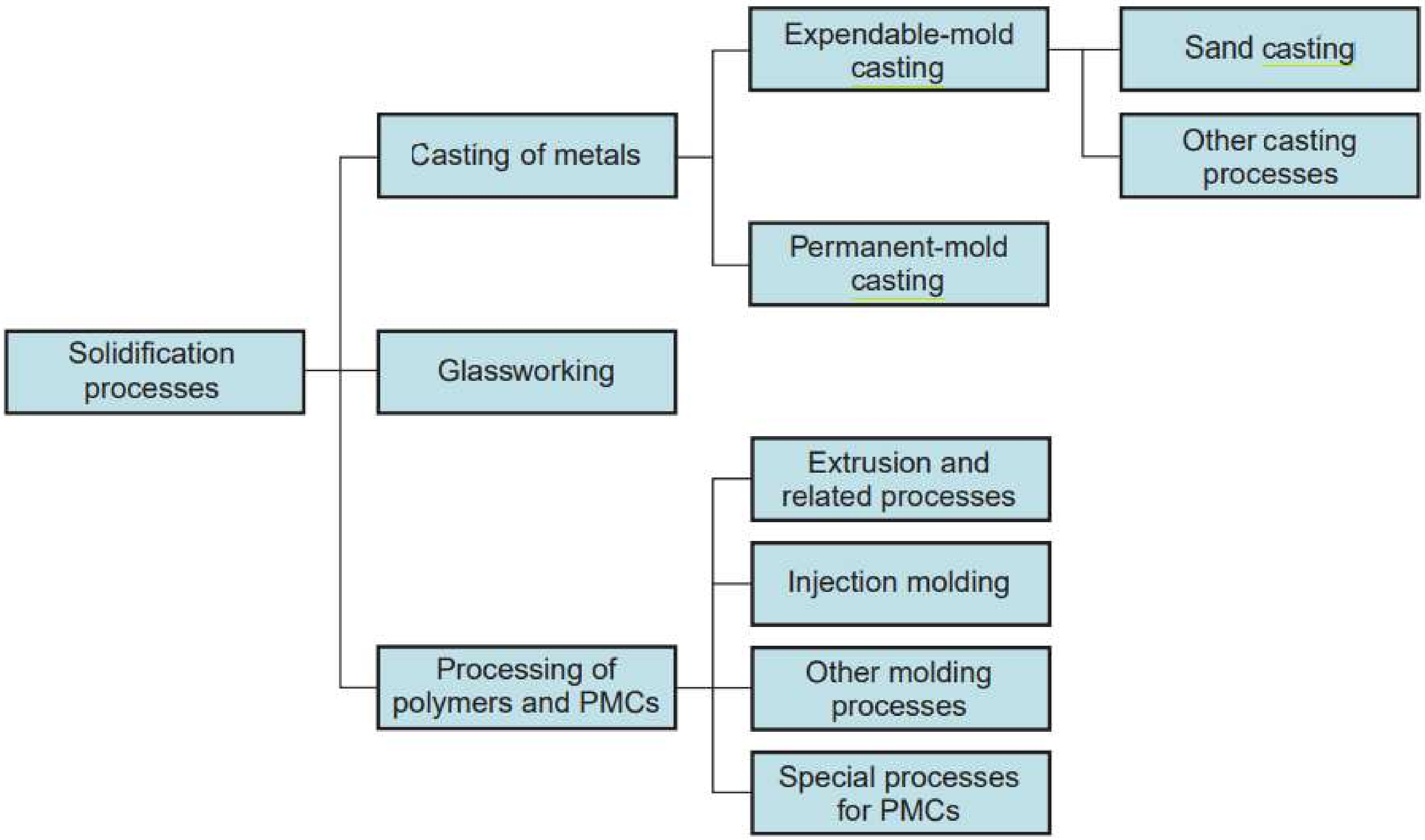
1. **Solidification processes -** starting material is a heated liquid or semifluid
2. **Particulate processing -** starting material consists of powders
3. **Deformation processes -** starting material is a ductile solid (commonly metal)
4. **Material removal processes -** starting material is a ductile or brittle solid

Solidification Processes

- Starting material is heated sufficiently to transform it into a liquid or highly plastic state
- Casting process at left and casting product at right



Classification of solidification processes.



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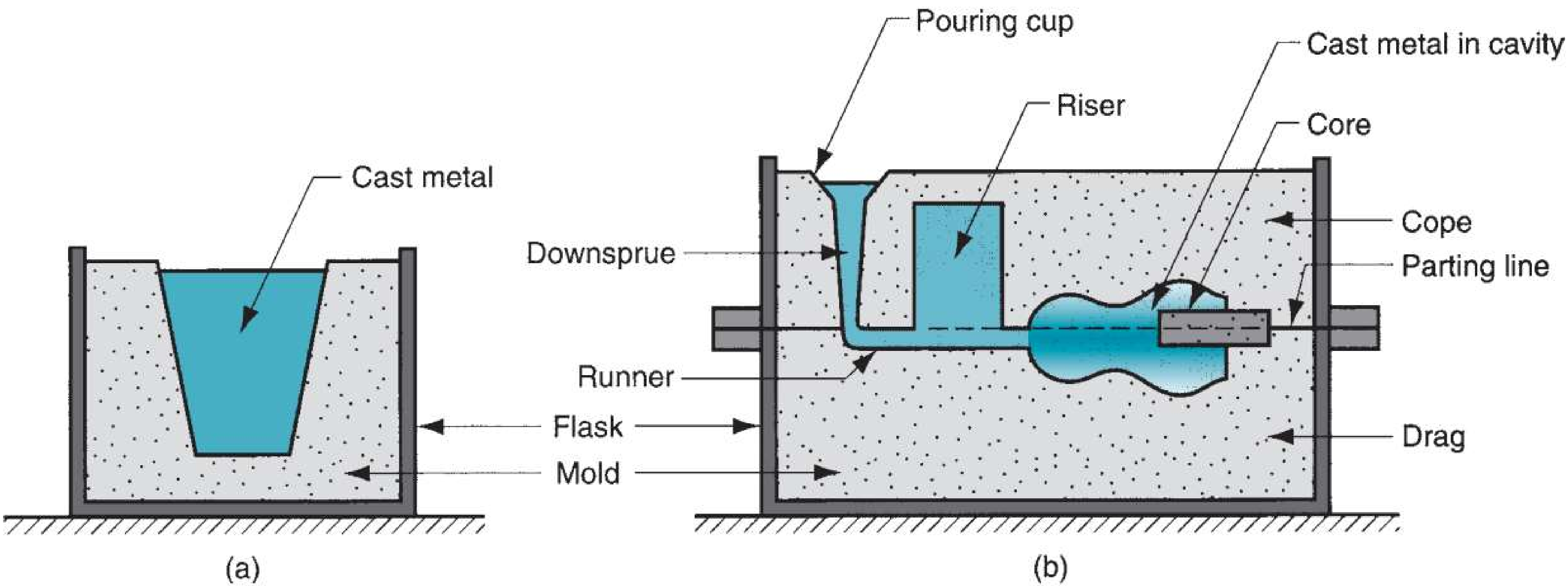
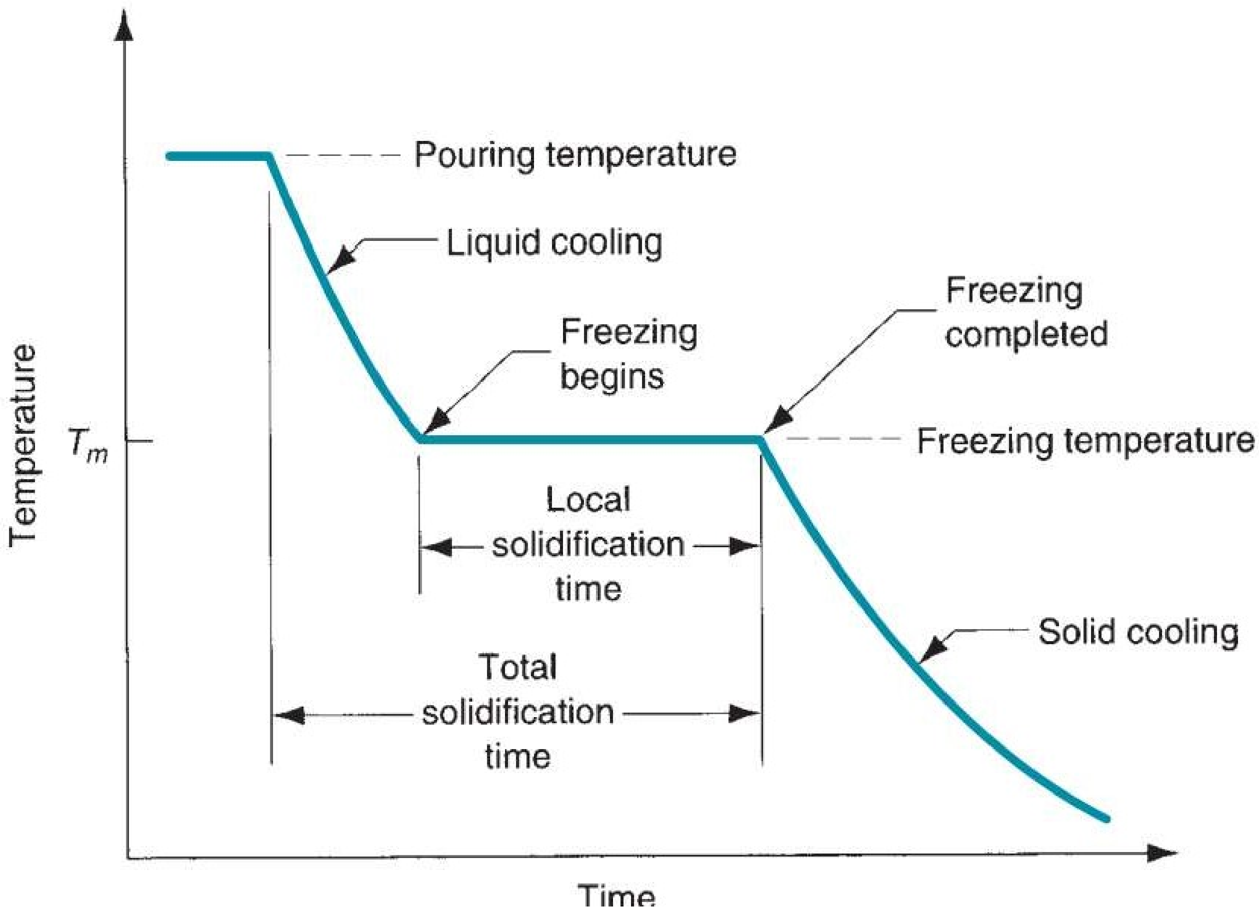
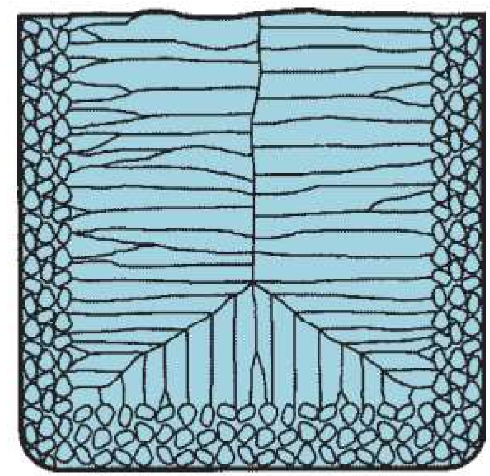
Advantages of Casting

- Casting can be used to create complex part geometries, including both external and internal shapes.
- Some casting processes are capable of producing parts to net shape. No further manufacturing operations are required to achieve the required geometry and dimensions of the parts. Other casting processes are near net shape,for which some additional shape processing is required (usually machining) in order to achieve accurate dimensions and details.
- Casting can be used to produce very large parts. Castings weighing more than 100 tons have been made.
- The casting process can be performed on any metal that can be heated to the liquid state.
- Some casting methods are quite suited to mass production.



Two forms of mold: (a) open mold, simply a container in the shape of the desired part; and (b) closed mold, in which the mold geometry is more complex and requires a gating system (passageway) leading into the cavity.

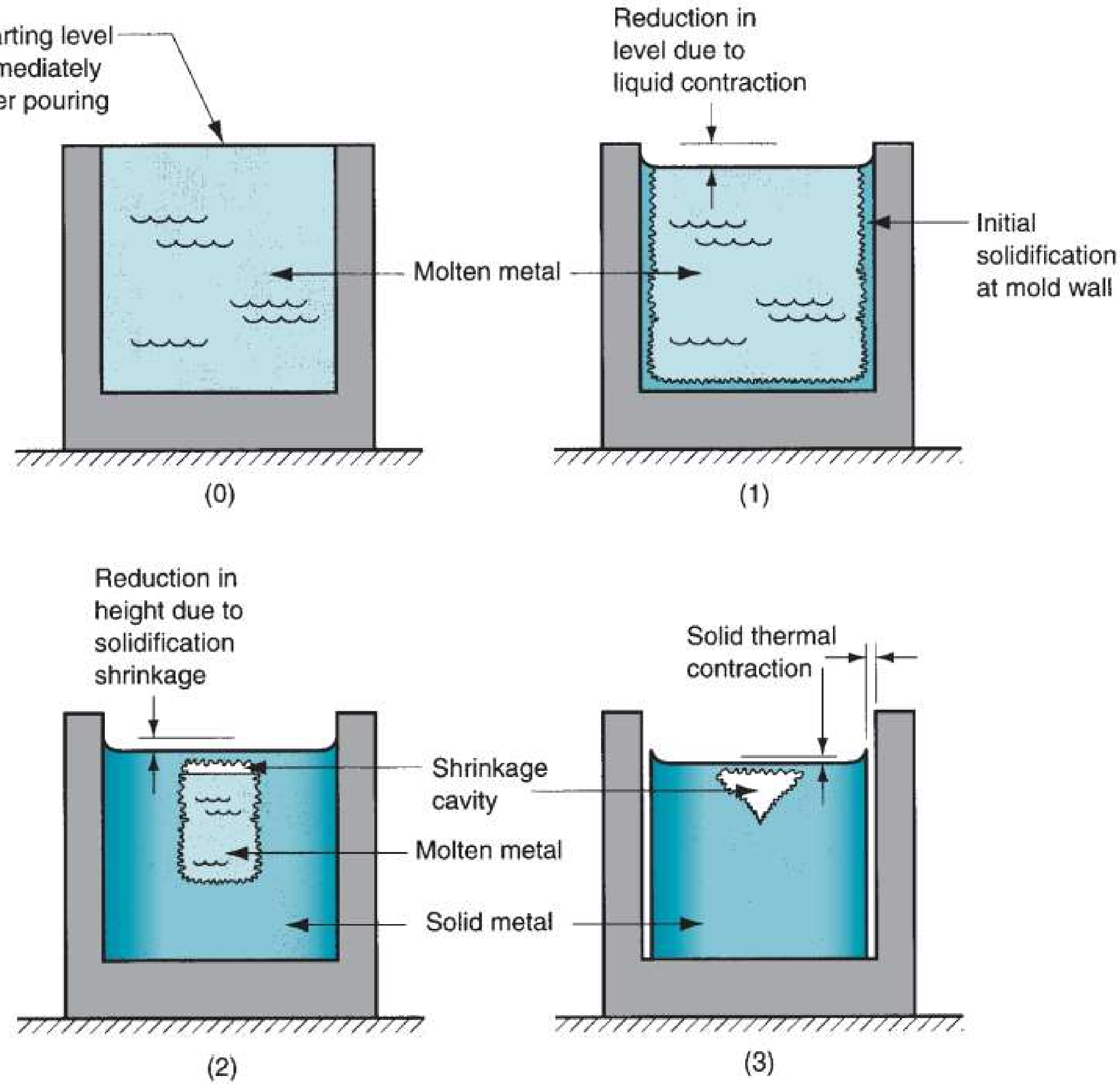




Characteristic grain structure in a casting of a pure metal, showing randomly oriented grains of small size near the mold wall, and large columnar grains oriented toward the center of the casting

Cooling curve for a pure metal during casting.

SHRINKAGE

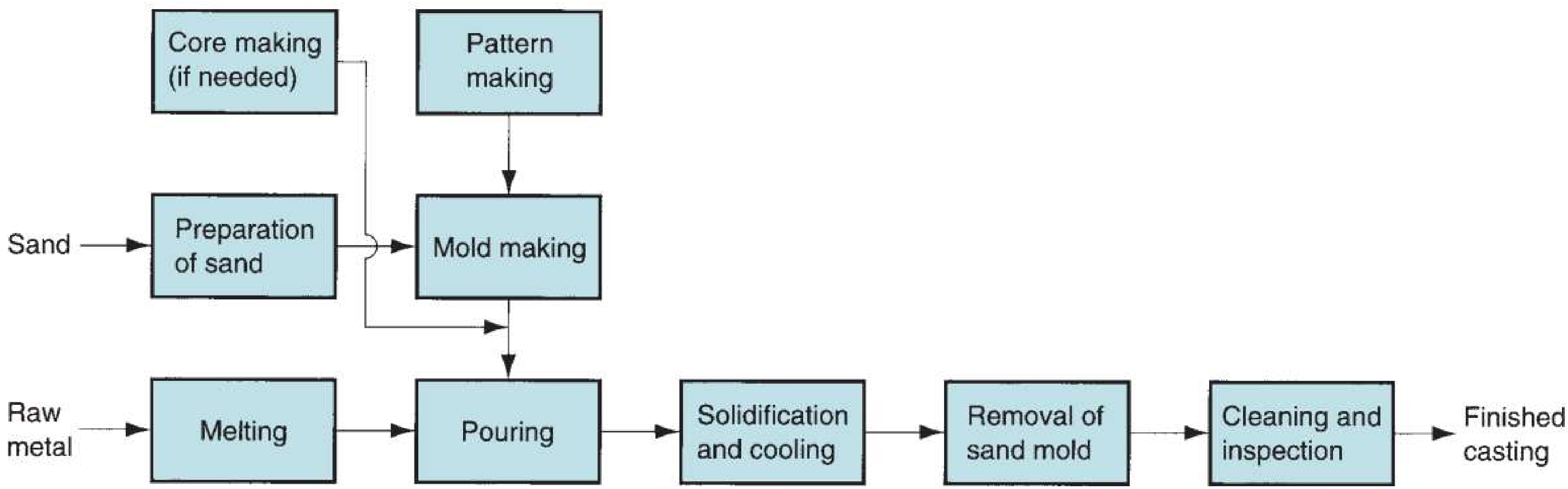


Shrinkage of a cylindrical casting during solidification and cooling: (0) starting level of molten metal immediately after pouring;

(1) reduction in level caused by liquid contraction during cooling; (2) reduction in height and formation of shrinkage cavity caused by solidification shrinkage; and

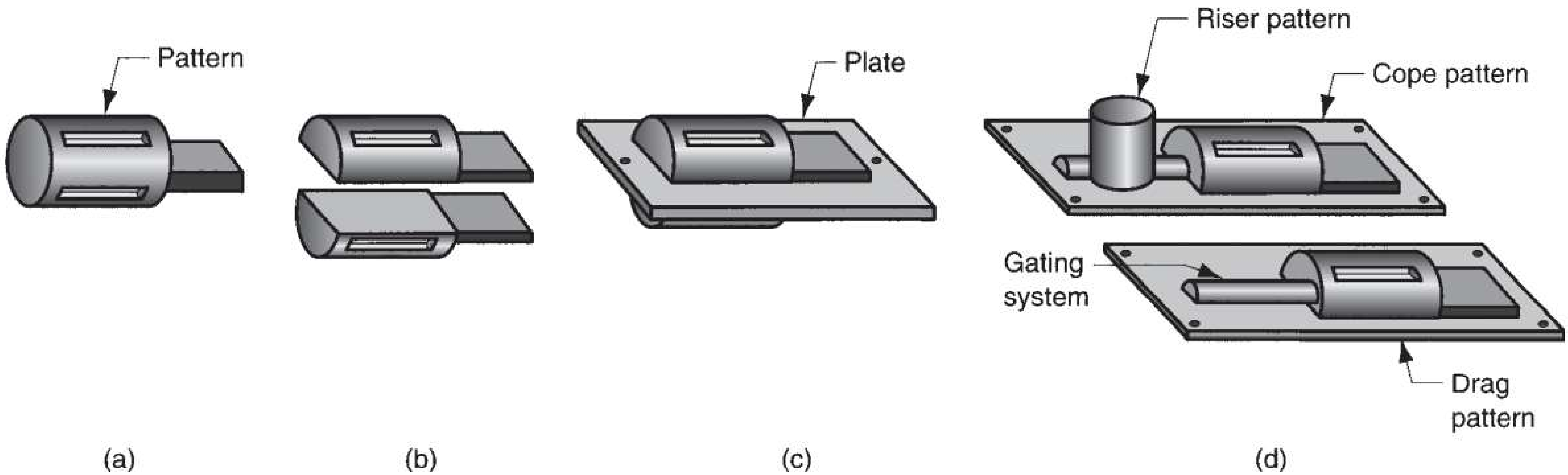
(2) (3) further reduction in height and diameter due to thermal contraction during cooling of the solid metal. For clarity, dimensional reductions are exaggerated in our sketches.

Steps in Sand Casting



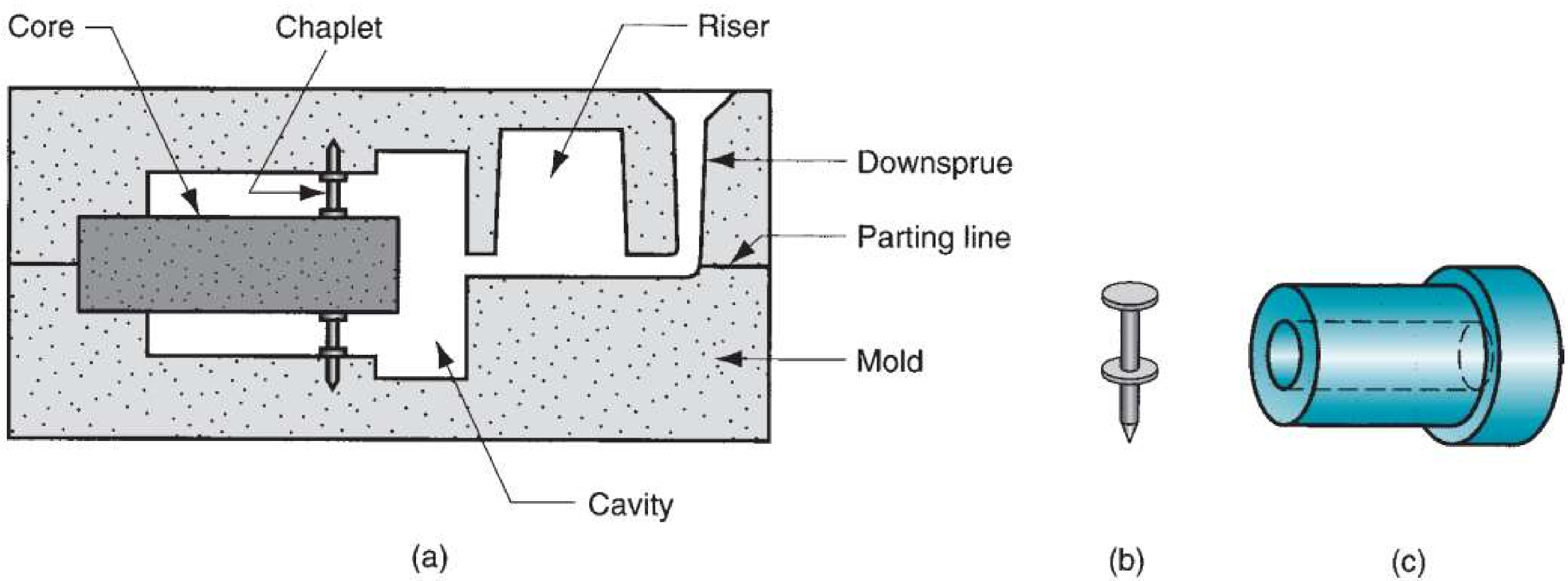
Steps in the production sequence in sand casting. The steps include not only the casting operation but also pattern making and mold making.

Types of Pattern



- https://youtu.be/tB2ga9mISks

Types of patterns used in sand casting: (a) solid pattern, (b) split pattern, (c) match-plate pattern, and (d) cope-and-drag pattern.

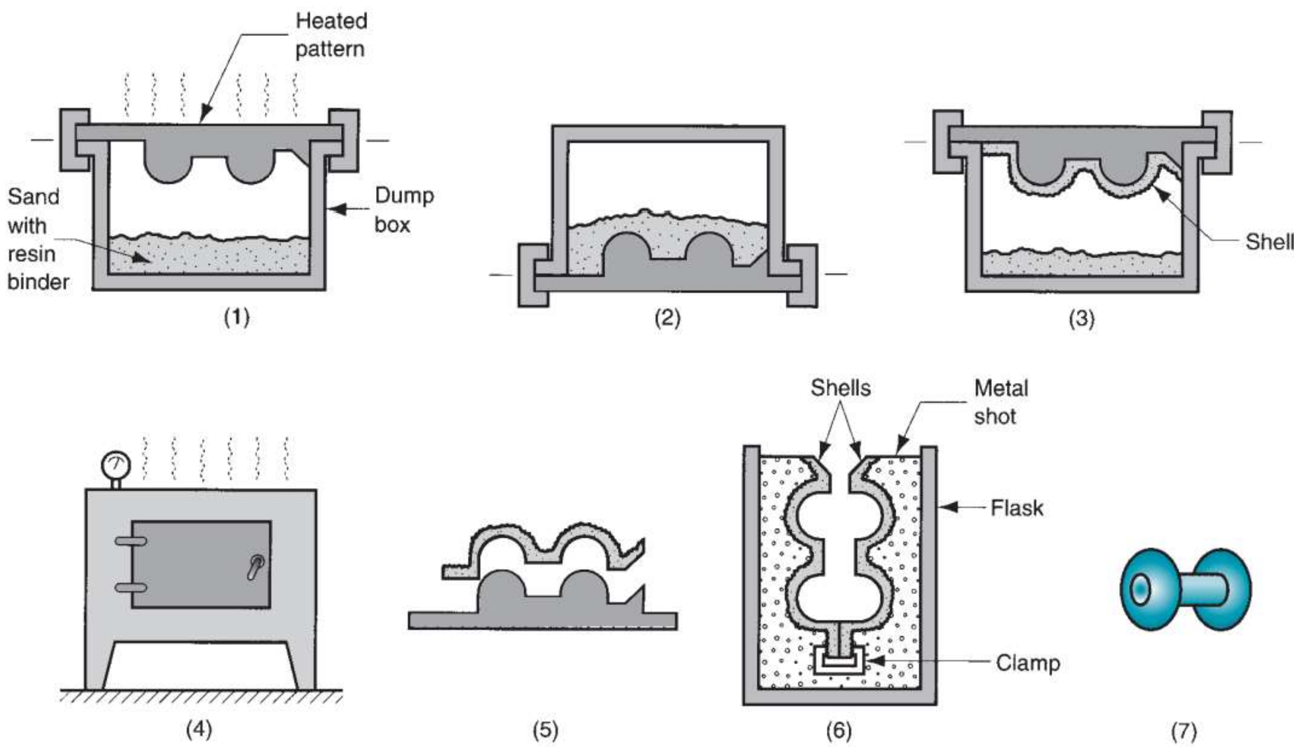


(a) Core held in place in the mold cavity by chaplets, (b) possible chaplet design, and (c) casting with internal cavity.

- https://youtu.be/1oZnxZj6-Ig?list=RDCMUCjE5YLiSC3zZAP15TUtzOfg

Other Expandable Mold Castings

- Shell Molding
- Vacuum Molding
- Expanded Polysterene Process
- Investment Casting

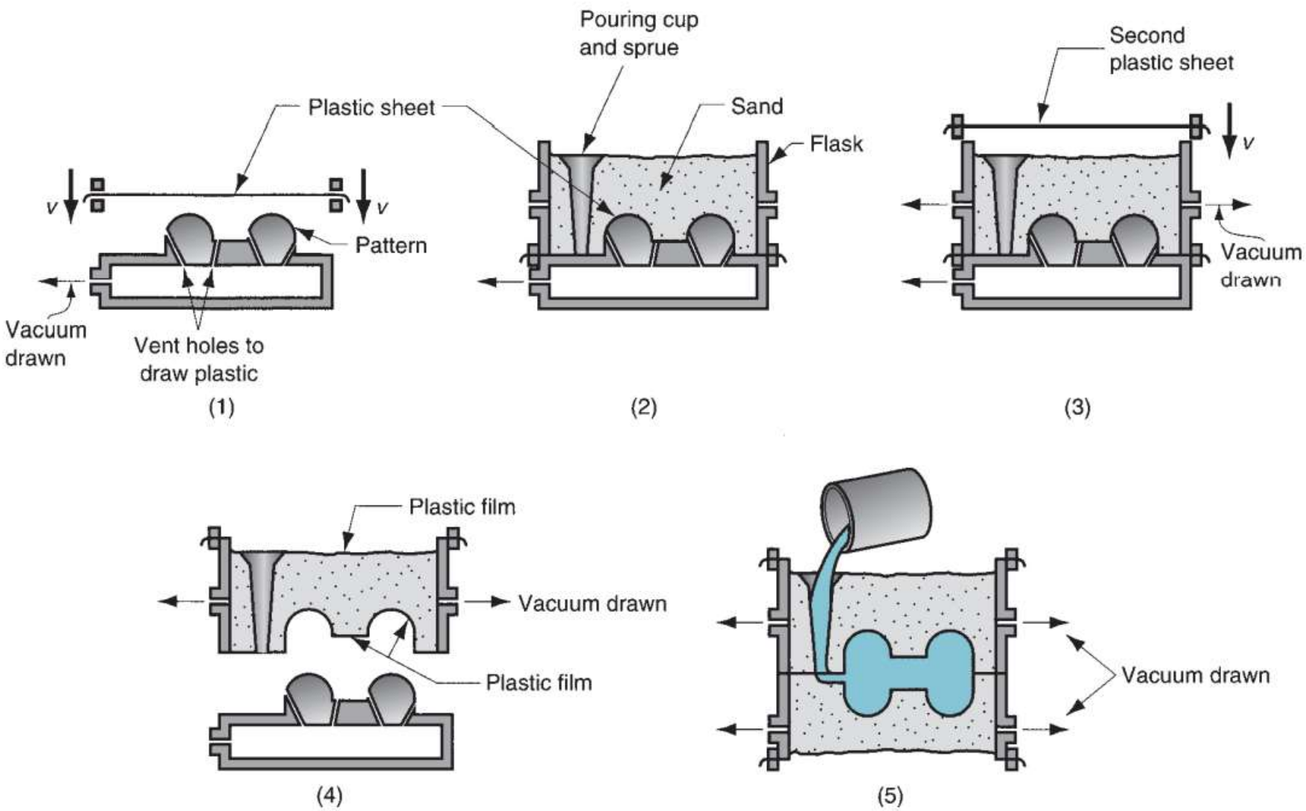


- https://youtu.be/x7mNoLA2e18

- https://youtu.be/WhS1ziBDxag

Steps in shell molding:

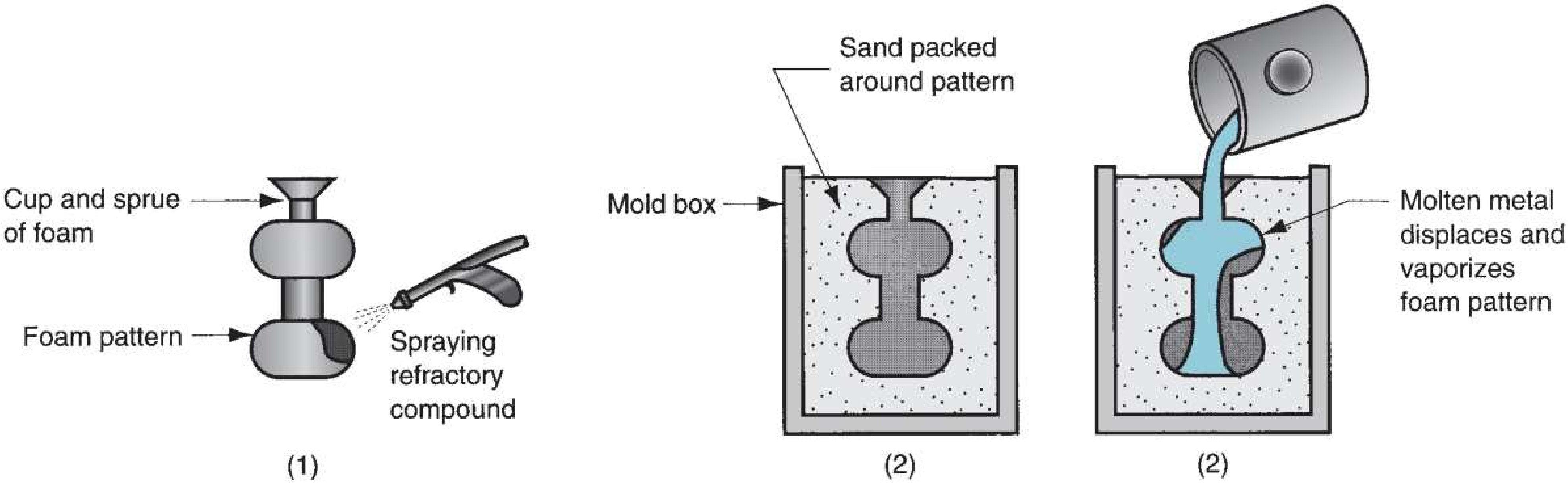
(1) a match-plate or cope-and-drag metal pattern is heated and placed over a box containing sand mixed with thermosetting resin;
(2) box is inverted so that sand and resin fall onto the hot pattern, causing a layer of the mixture to partially cure on the surface to form a hard shell;
(3) box is repositioned so that loose, uncured particles drop away;
(4) sand shell is heated in oven for several minutes to complete curing;
(5) shell mold is stripped from the pattern;
(6) two halves of the shell mold are assembled, supported by sand or metal shot in a box, and pouring is accomplished. The finished casting with sprue removed is shown in (7)



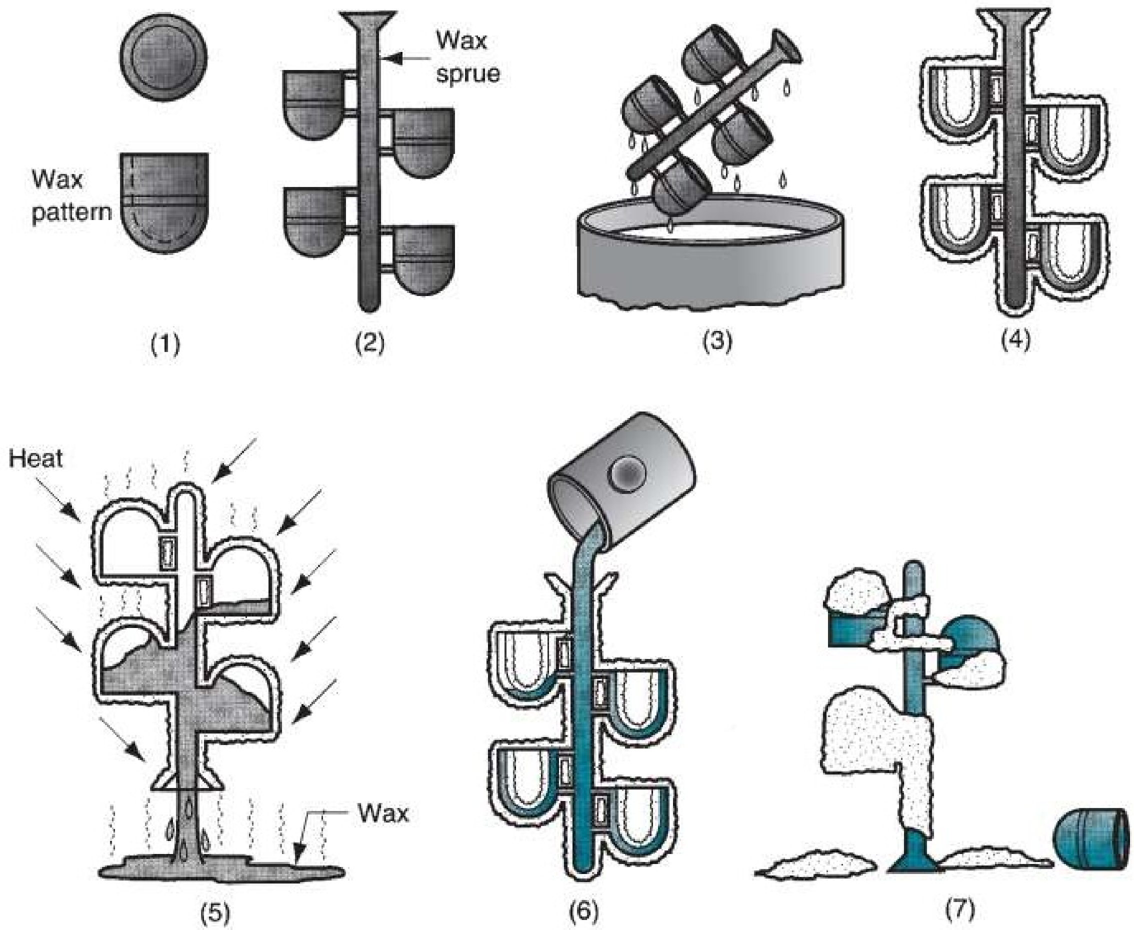
Steps in vacuum molding:

(1) a thin sheet of preheated plastic is drawn over a match-plate or cope-and-drag pattern by vacuum—the pattern has small vent holes to facilitate vacuum forming;
(2) a specially designed flask is placed over the pattern plate and filled with sand, and a sprue and pouring cup are formed in the sand;
(3) another thin plastic sheet is placed over the flask, and a vacuum is drawn that causes the sand grains to be held together, forming a rigid mold;
(4) the vacuum on the mold pattern is released to permit the pattern to be stripped from the mold;
(5) this mold is assembled with its matching half to form the cope and drag, and with vacuum maintained on both halves, pouring is accomplished. The plastic sheet quickly burns away on contacting the molten metal. After solidification, nearly all of the sand can be recovered for reuse.

Expanded polystyrene casting process



Expanded polystyrene casting process: (1) pattern of polystyrene is coated with refractory compound; (2) foam pattern is placed in mold box, and sand is compacted around the pattern; and (3) molten metal is poured into the portion of the pattern that forms the pouring cup and sprue. As the metal enters the mold, the polystyrene foam is vaporized ahead of the advancing liquid, thus allowing the resulting mold cavity to be filled.

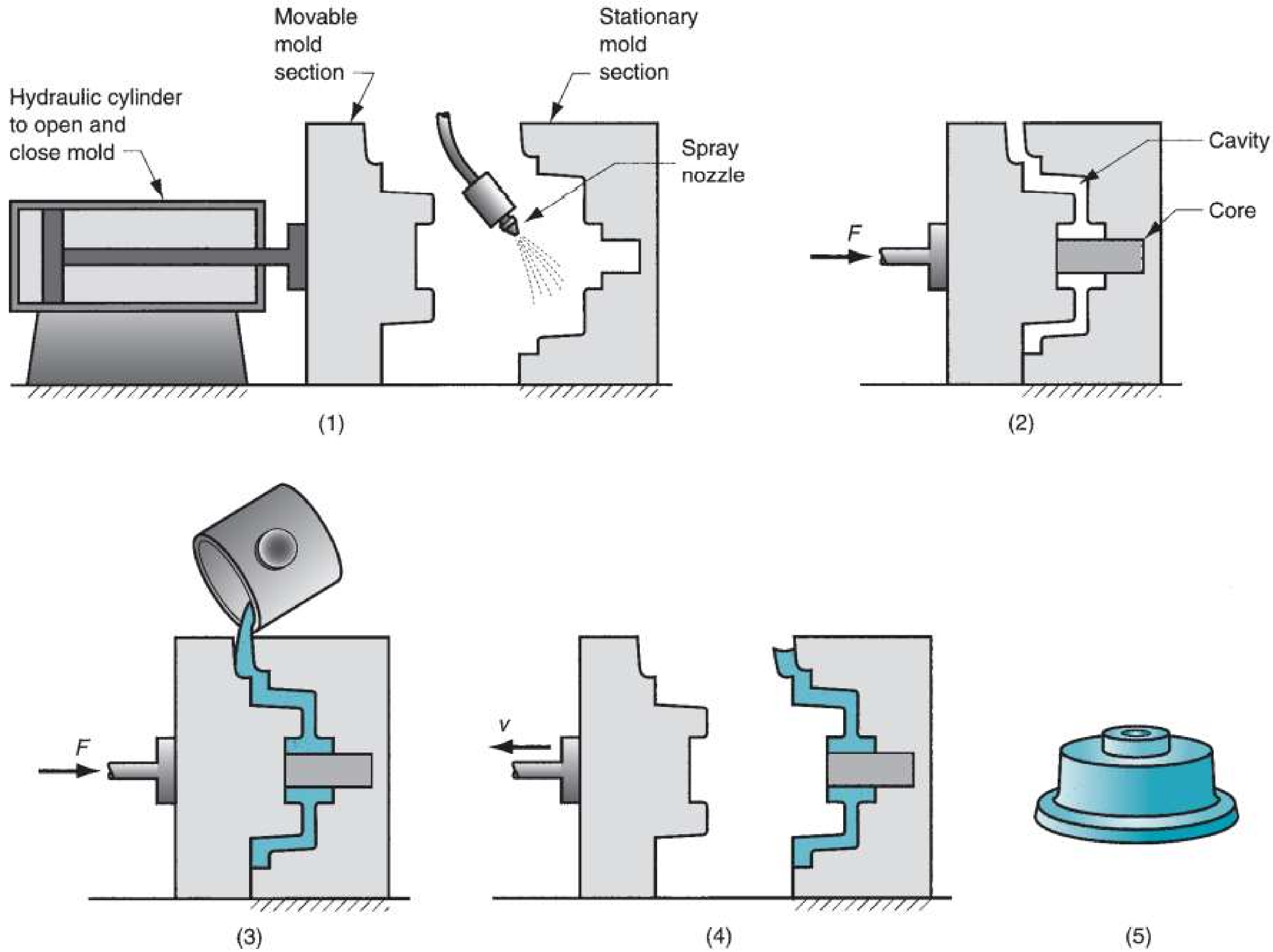


Steps in investment casting:

(1) wax patterns are produced;
(2) several patterns are attached to a sprue to form a pattern tree;
(3) the pattern tree is coated with a thin layer of refractory material;
(4) the full mold is formed by covering the coated tree with sufficient refractory material to make it rigid;
(5) the mold is held in an inverted position and heated to melt the wax and permit it to drip out of the cavity;
(6) the mold is preheated to a high temperature, which ensures that all contaminants are eliminated from the mold; it also permits the liquid metal to flow more easily into the detailed cavity; the molten metal is poured; it solidifies; and
(7) the mold is broken away from the finished casting. Parts are separated from the sprue.

- https://youtu.be/eJL-31__sO8?list=RDCMUCjE5YLiSC3zZAP15TUtzOfg

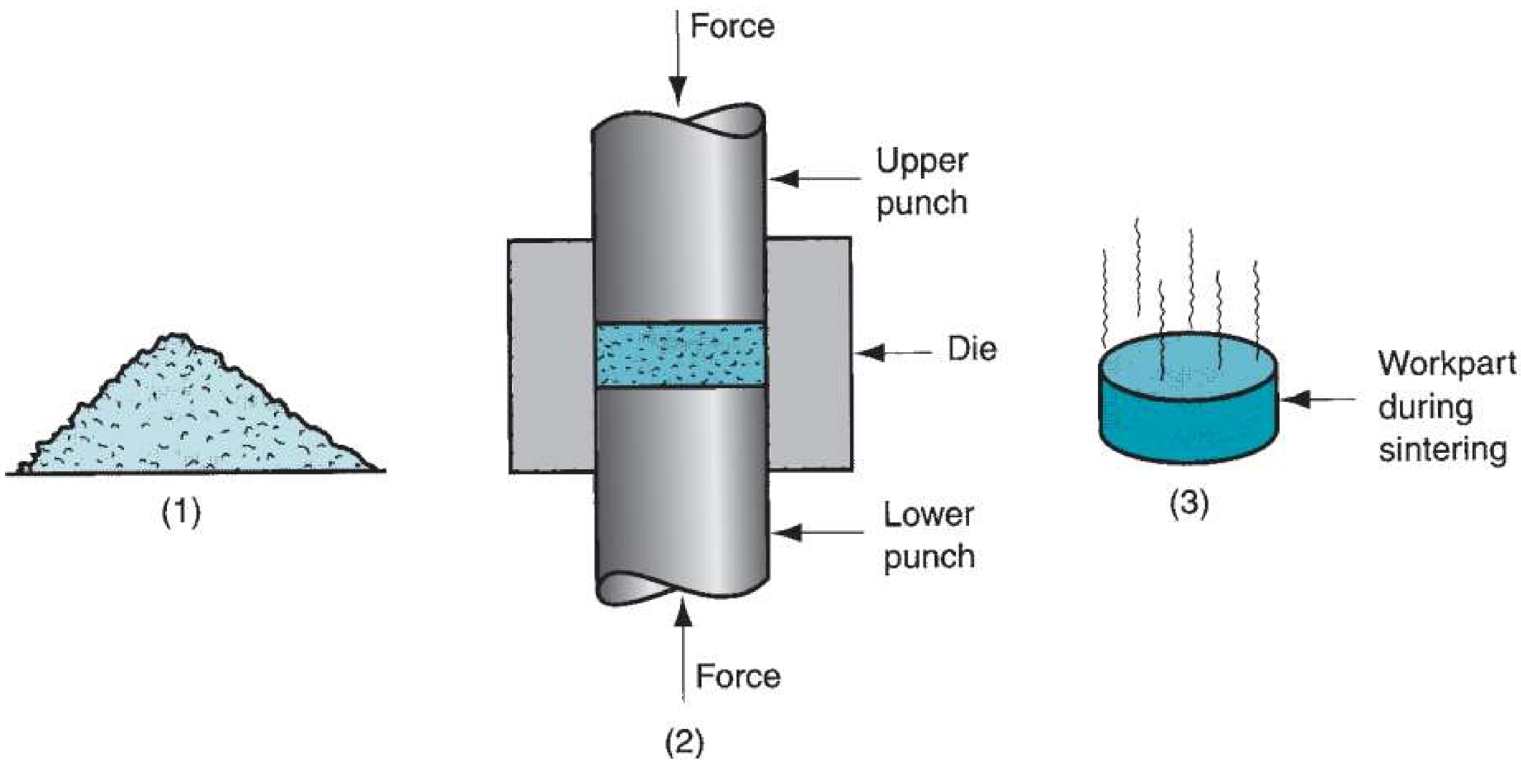
PERMANENT-MOLD CASTING PROCESSES



Steps in permanent-mold casting:
(1) mold is preheated and coated;
(2) cores (if used) are inserted, and mold is closed;
(3) molten metal is poured into the mold; and
(4) mold is opened. Finished part is shown in (5).

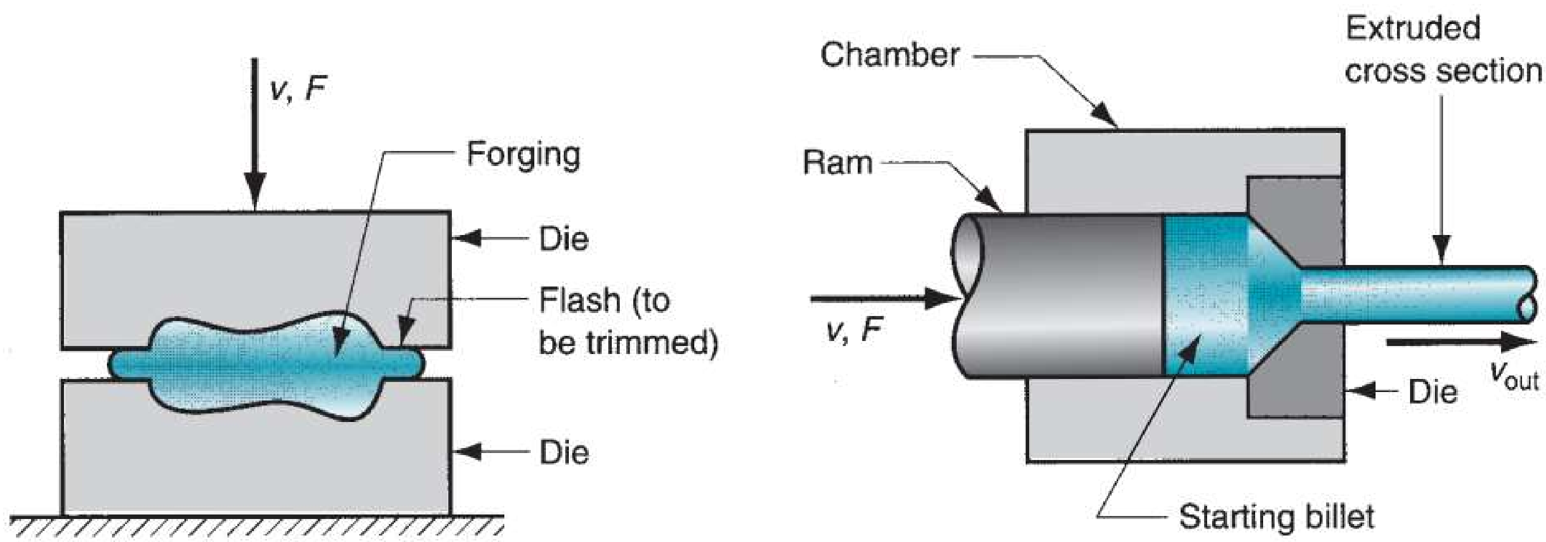
Particulate Processing

- (1) Starting materials are metal or ceramic powders, which are (2) pressed and (3) sintered



Deformation Processes

- Starting workpart is shaped by application of forces that exceed the yield strength of the material
- Examples: (a) forging and (b) extrusion



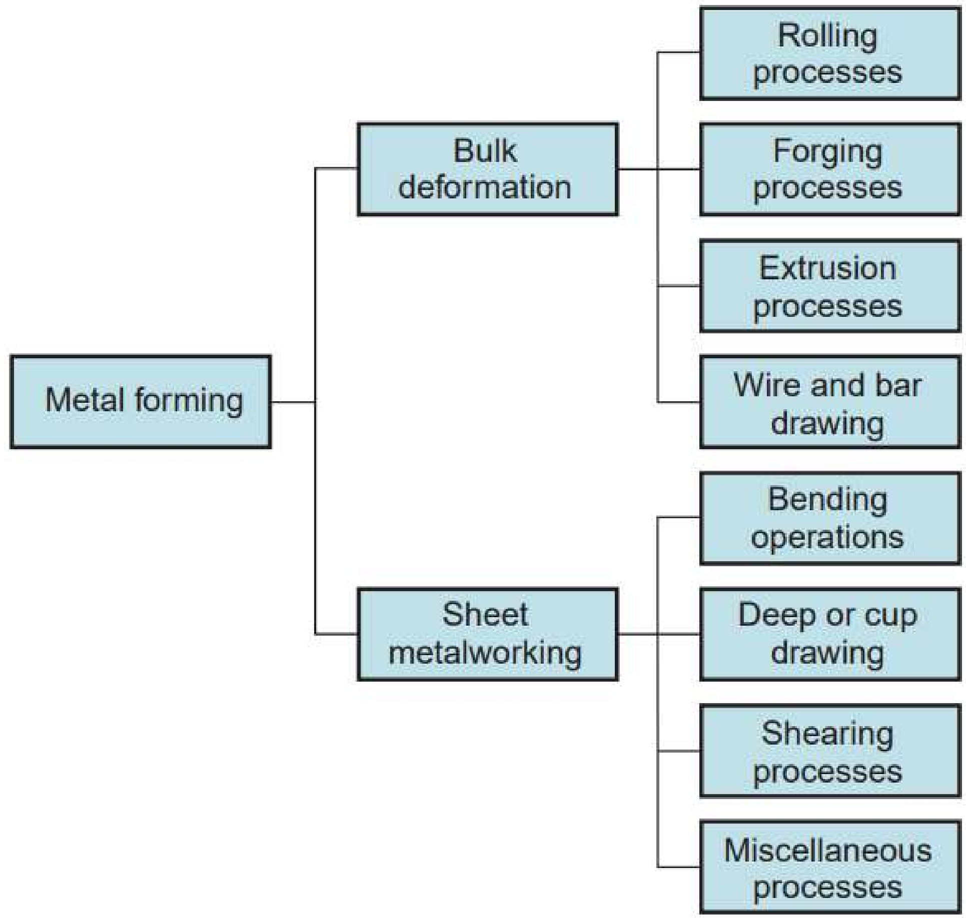
(a) (b)

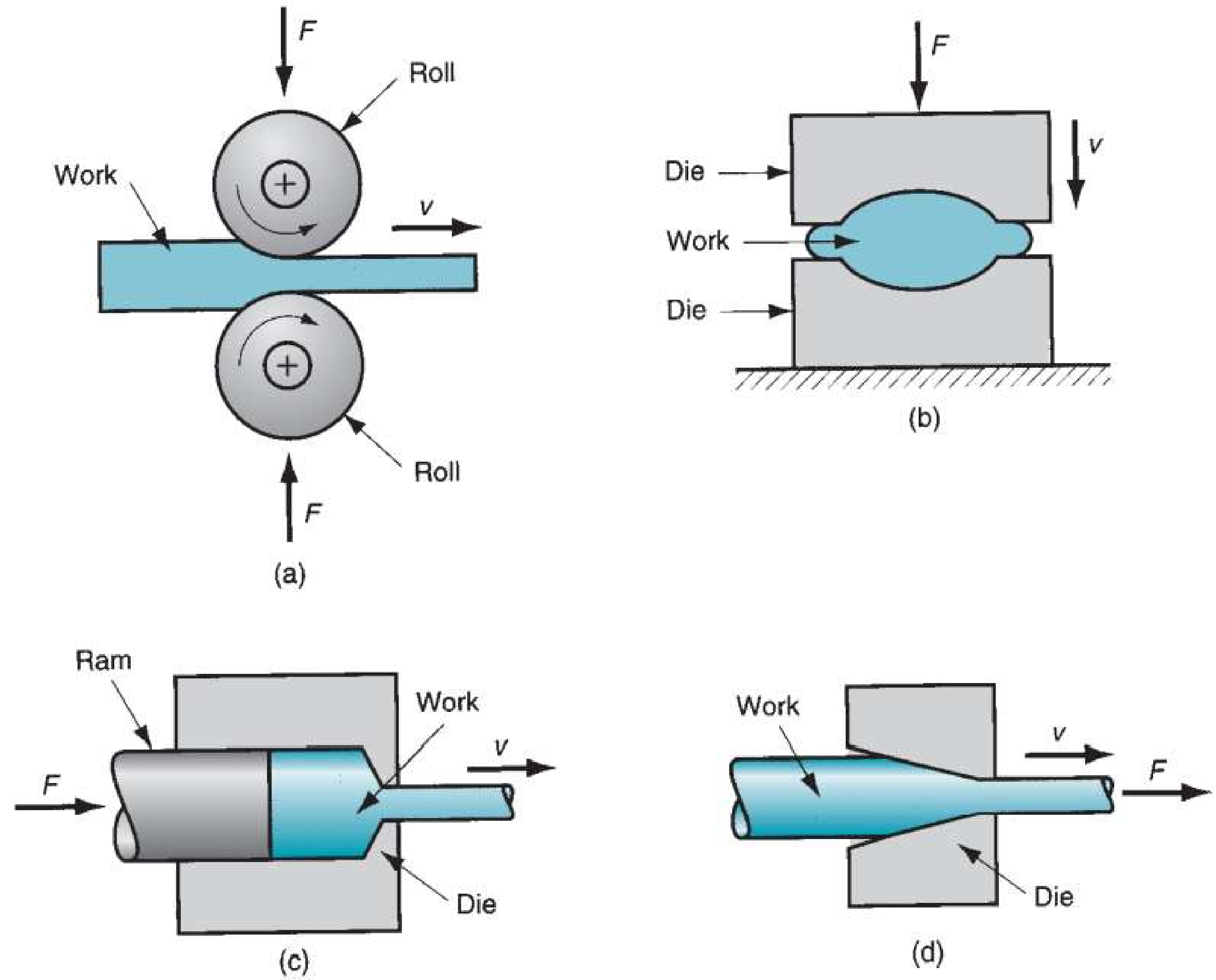
- Metal forming includes a large group of manufacturing processes in which plastic deformation is used to change the shape of metal workpieces.

- Deformation results from the use of a tool, usually called a die in metal forming, which applies stresses that exceed the yield strength of the metal.

- The metal therefore deforms to take a shape determined by the geometry of the die.

Classification of metal forming operations





Basic bulk deformation processes: (a) rolling, (b) forging, (c) extrusion, and (d) drawing. Relative motion in the operations is indicated by v; forces are indicated by F.

Bulk Deformation Processes

- **Rolling**. This is a compressive deformation process in which the thickness of a slab or plate is reduced by two opposing cylindrical tools called rolls. The rolls rotate so as to draw the work into the gap between them and squeeze it.
- **Forging**. In forging, a workpiece is compressed between two opposing dies, so that the die shapes are imparted to the work. Forging is traditionally a hot working process, but many types of forging are performed cold.
- **Extrusion**. This is a compression process in which the work metal is forced to flow through a die opening, thereby taking the shape of the opening as its own cross section.
- **Drawing**. In this forming process, the diameter of a round wire or bar is reduced by pulling it through a die opening.

Basic sheet metalworking operations: (a) bending, (b) drawing, and (c) shearing: (1) as punch first contacts sheet, and (2) after cutting. Force and relative motion in these operations are indicated by F and v.