ME 222: Manufacturing Technology I

(3-0-0-6)

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Department of Mechanical Engineering

IIT Guwahati

Course Contents

Related course: ME110, ME225, ME312, ME213

Module	
1	Introduction to manufacturing processes
2	Moulding materials and mould design; Pattern types and design. **Casting** processes: sand casting, investment casting, pressure die casting, centrifugal casting, continuous casting; Casting analysis; Casting defects and their remedies
3	**Metal forming** Processes: Various metal forming techniques and their analysis, viz., forging, rolling, extrusion, wire drawing, sheet metal working; Super plastic deformation; Metal forming defects
4	**Metal joining** processes: brazing, soldering, welding; Solid state welding; resistance welding; arc welding; gas welding; Welding defects
5	**Polymer fabrication** methods viz., Injection moulding, Compression moulding, Transfer moulding, Thermoforming
6	**Composite fabrication** methods viz., Compression moulding, Vacuum moulding, Prepregs fabrication, Filament winding
7	**Additive manufacturing** / 3D printing (metal & polymers) ceramic left
8	**Powder metallurgy** and its applications

foundry metal

welding

metal

Texts and References

Texts:

[1] **A. Ghosh and A. K. Mallik**, **Manufacturing Science**, Wiley Eastern, 2010

[2] P. N. Rao, Manufacturing Technology: Foundry, Forming And Welding, Tata McGraw Hill, 2017.

[3] M. P. Groover, Introduction to Manufacturing Processes, Wiley, 2011

[4] M. P. Groover, Principles of Modern Manufacturing: Materials, Processes and Systems, Wiley (India edition), 2019

References:

[1] J. S. Campbell, Principles of Manufacturing Materials and Processes, Tata McGraw Hill, 1995.

[2] M. C. Flemings, Solidification Processing, Tata McGraw Hill, 1982.

[3] P. C. Pandey and C. K. Singh, Production Engineering Sciences, Standard Publishers Ltd., 2013.

[4] S. Kalpakjian and S. R. Schmid, Manufacturing Processes for Engineering Materials, Pearson education, 6th edition, 2016.

[5] S. Kalpakjian and S. R. Schmid, Manufacturing Engineering and Technology, Pearson education, 7th edition, 2016

Evaluation scheme

Evaluation scheme: Quiz: 20%

Mid-semester exam: 30%

End-semester exam: 50%

Assignment/Tutorial: Optional

Class schedule: Monday: 9:00 AM – 9:55 AM

Tuesday: 10:00 AM – 10:55 AM

Wednesday: 11:00 AM – 11:55 AM

Venue: Room 5202, Core-V

Instructor: Dr. Prasenjit Khanikar
Office: Room No. 301, C-Block, Core-I, Academic Complex
email: pkhanikar@iitg.ac.in
phone: 0361-258-3438

What is ‘manufacturing’ ?

‘Manufacture’ → Year 1567

‘Manufacturing’ → Year 1683

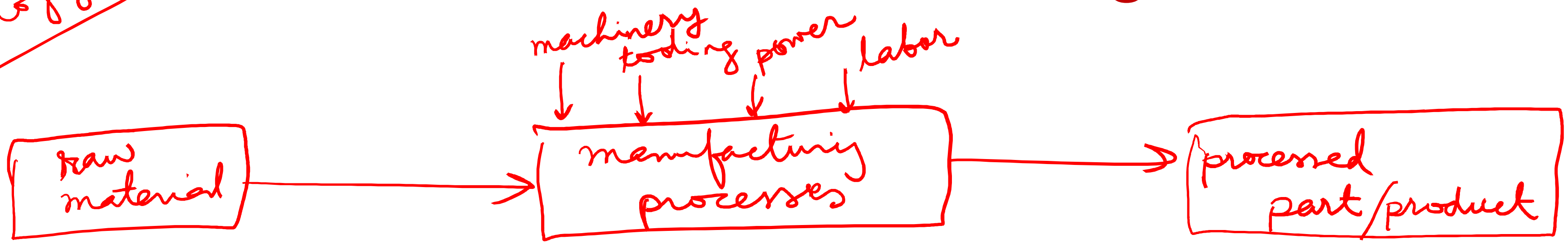
‘Production’ → 15^{th} Century

Origin:
(Latin) “manu factus” means “made by hand”

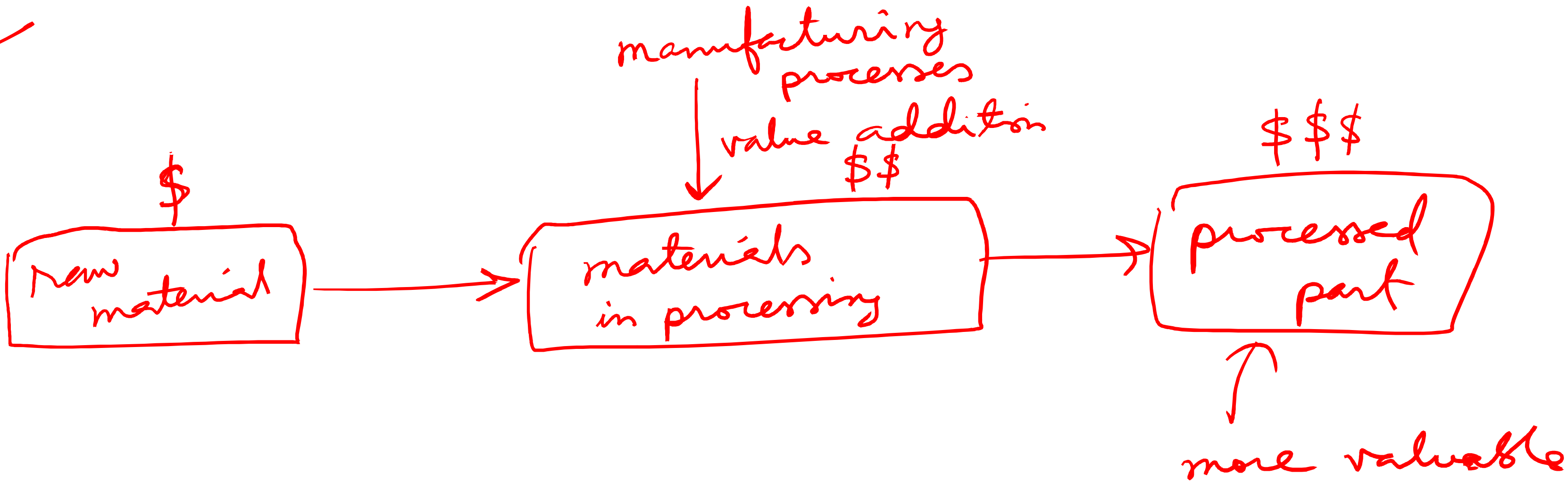
Although ‘production’ and ‘manufacturing’ are interchangeably used, ‘production’ is broader than ‘manufacturing’, e.g., crude oil production (not manufacturing)

What is ‘manufacturing’ ?

Technology



Economy



Manufacturing Technology

- ‘Technology’ → Application of science to provide needed or desired things to society and its members
- We use machinery and computer for manufacturing
- While manufacturing processes use technology, most technology products are manufactured
- Most modern manufacturing is accomplished by automated and computer-controlled machinery

5th or 6th January, 2024
https://www.facebook.com/Owwstin

Austin Armstrong · Follow
2d ·

This is a 1000 gram iron bar. It's raw value is around $100.

If you decide to make horseshoes, its value would increase to $250.

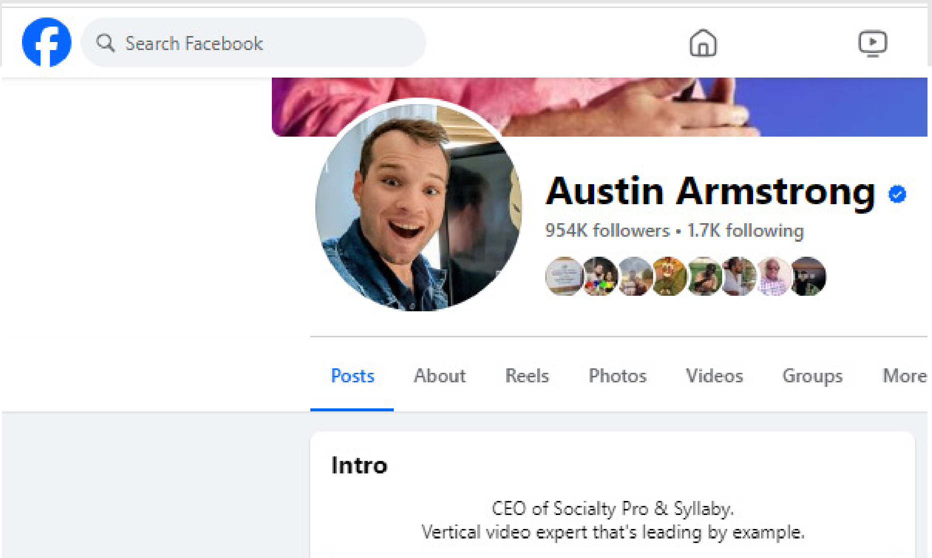
If, instead, you decided to make sewing needles, the value would increase to about $70,000.

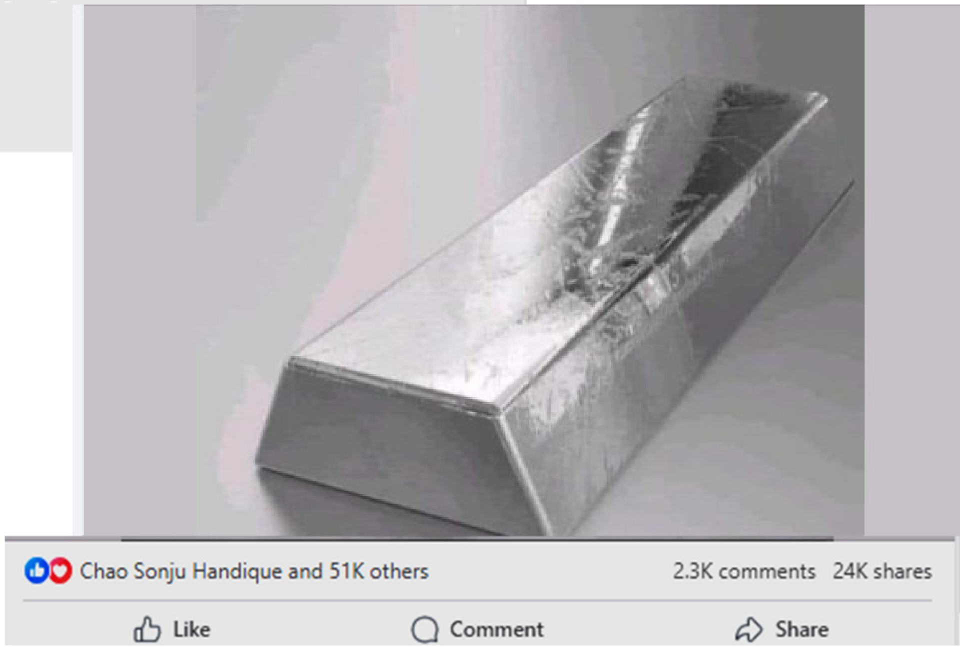
If you decided to produce watch springs and gears, the value would increase to about $6 Million.

However still, if you decided to manufacture precision laser components out of it like ones used in lithography, it'll be worth $15 Million.

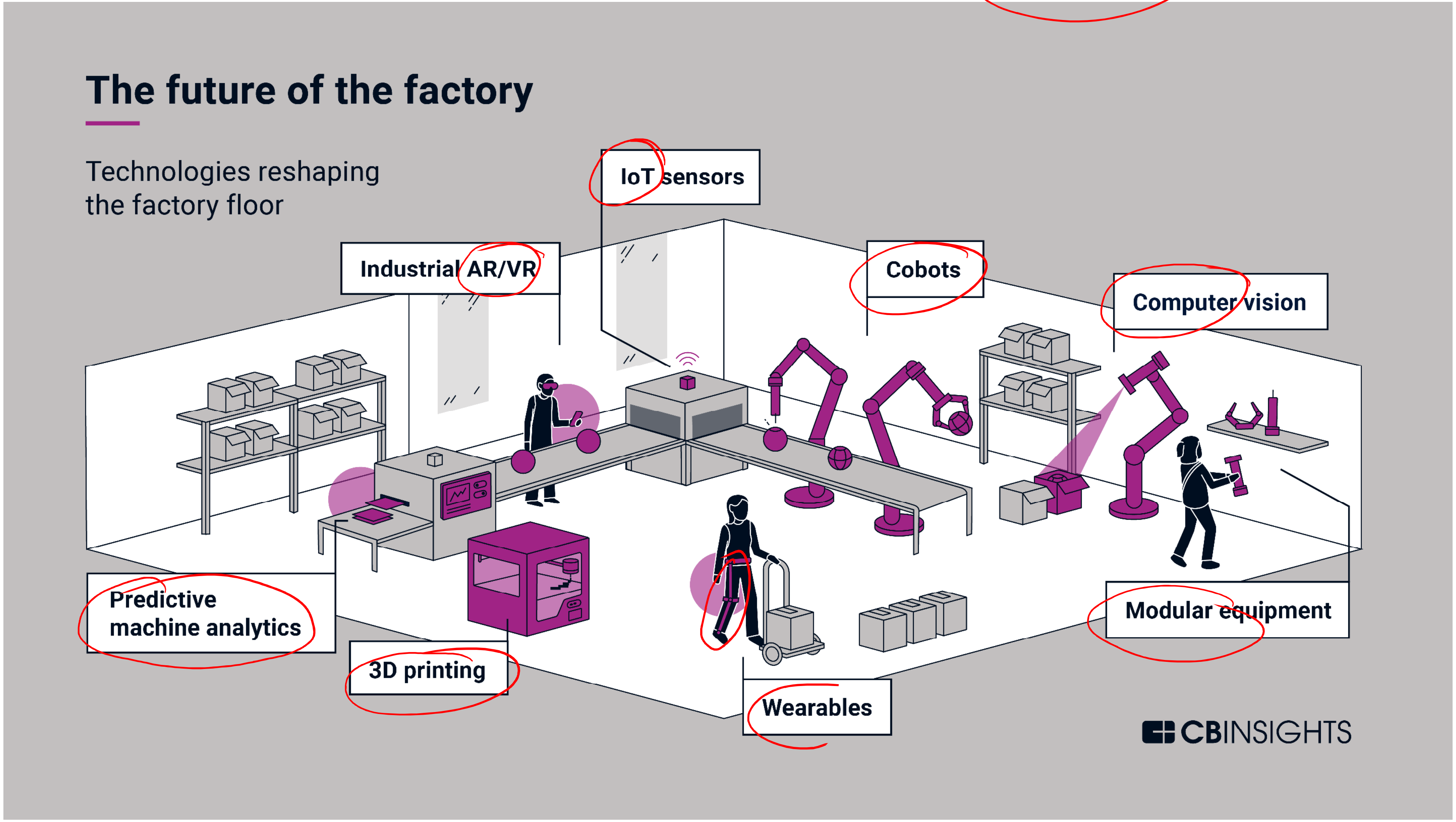
Your value is not just what you are made of - but above all -in what ways you can make the best of who you are.

🙏





Future of Manufacturing and India



Module 1: Introduction to Manufacturing Processes

- ✓ **Manufacturing processes**
- ✓ **Materials processing technologies**
- ✓ **Types and properties of engineered materials**
- ✓ **Evaluation of properties of manufactured products**

Manufacturing processes

- Conversion of resource into raw materials → mining and metallurgy
- Raw materials to final product → manufacturing processes

Casting → Machining, Forming → Joining, Finishing, Assembly

Understanding of Manufacturing process →

Design – Most economic manner

Production – Selection of important process parameters

Development of new techniques and modification of existing technologies

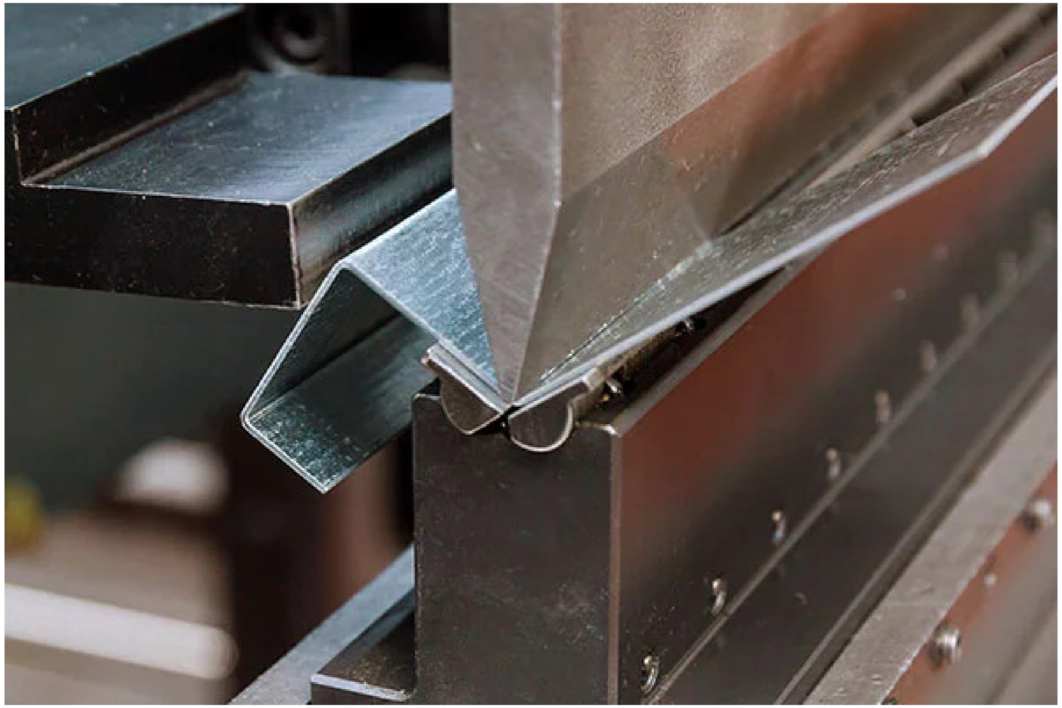
Production process that can not be solved by conventional methods

→**Unconventional manufacturing processes**

Different manufacturing processes

Hot rolling

www.montanstahl.com



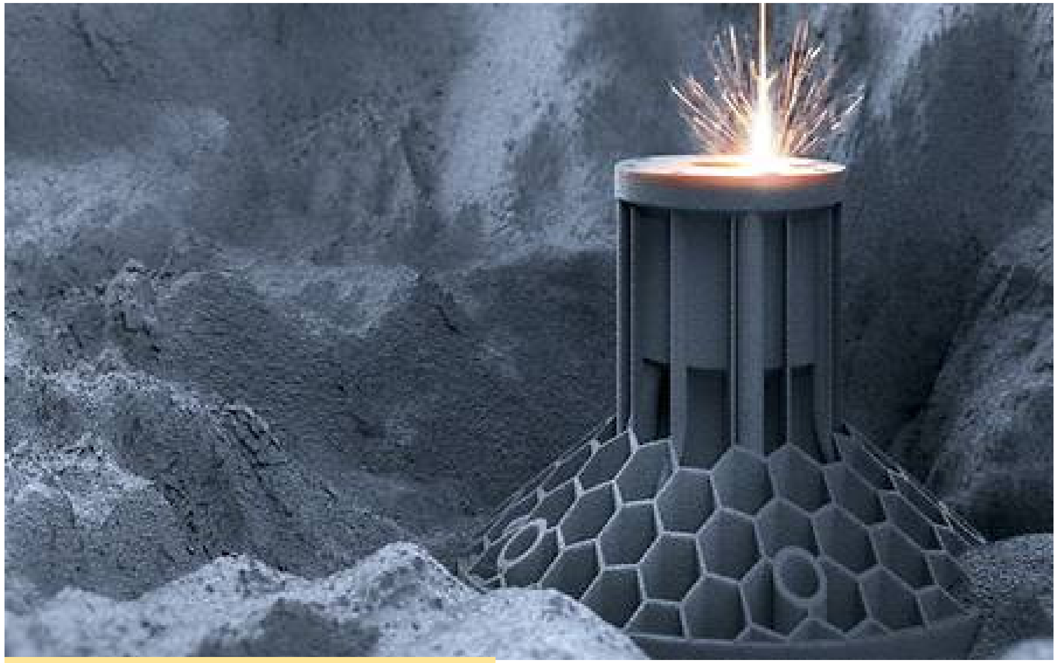
www.lsengineering.co.uk

Sheet metal forming

Different manufacturing processes

www.makeagif.com

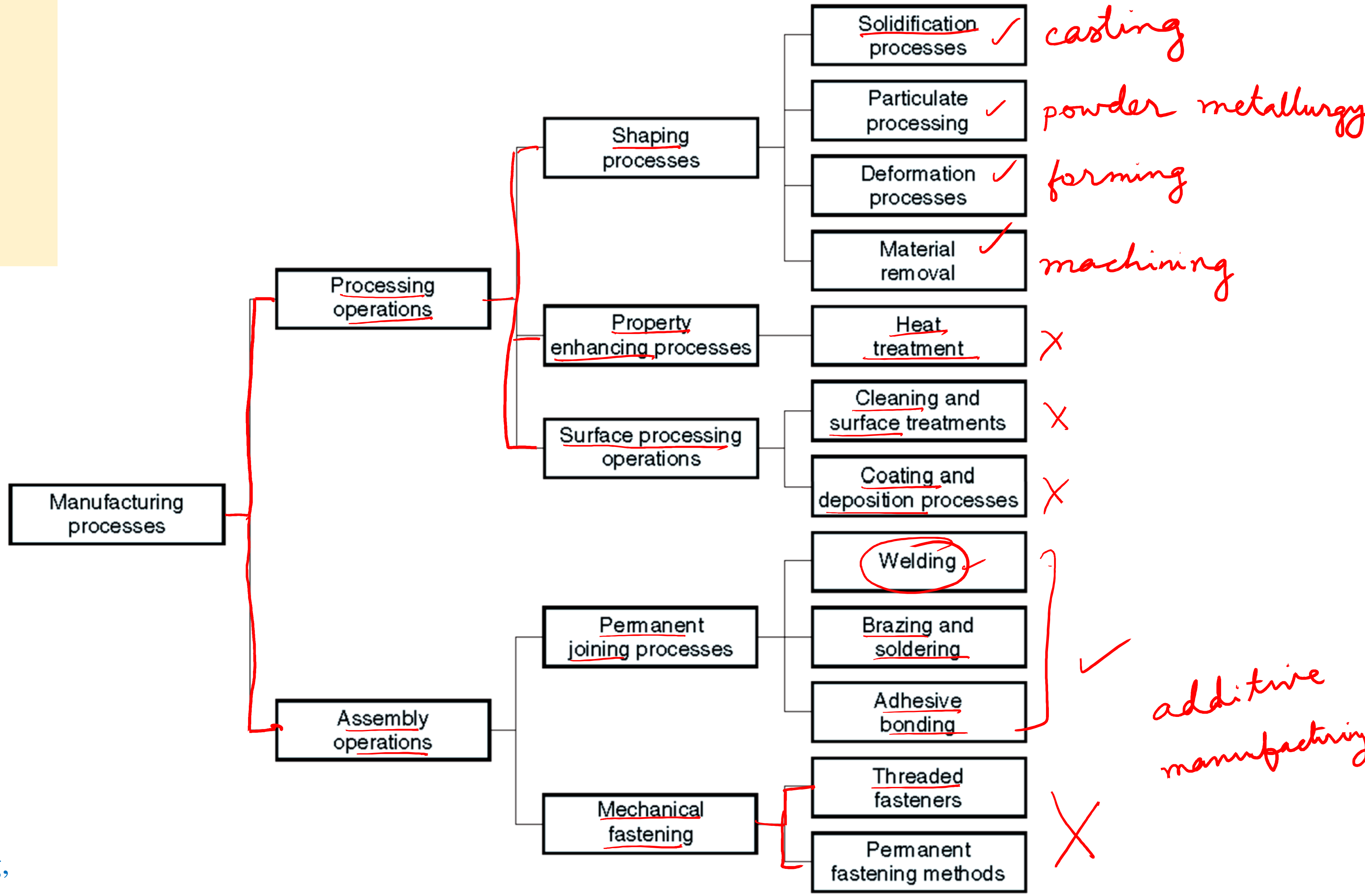
Additive manufacturing



Additive manufacturing

www.theadditivemanufacturing.com

One Classification of Manufacturing Processes



Courtesy:
Principles of Modern Manufacturing,
M. P. Groover

Selection of Manufacturing Processes

Fabrication of products

- **Single manufacturing process**
- **Multiple manufacturing processes in sequence**

Factors decides the selection of manufacturing process

- **Shape of the part/product**
- **Material properties**
  - **Castability/ formability/ weldability/ machinability**
  - e.g., metal forming of hard and brittle material is difficult, casting and machining may be preferred
- Change of material properties during manufacturing
  - e.g., metal forming at room temperature leads to a part with high strength, high hardness and low ductility
- **Size of the part/product**
  - e.g., limited size in additive manufacturing, micromanufacturing, nanomanufacturing
- **Production rate**
- **Production cost**

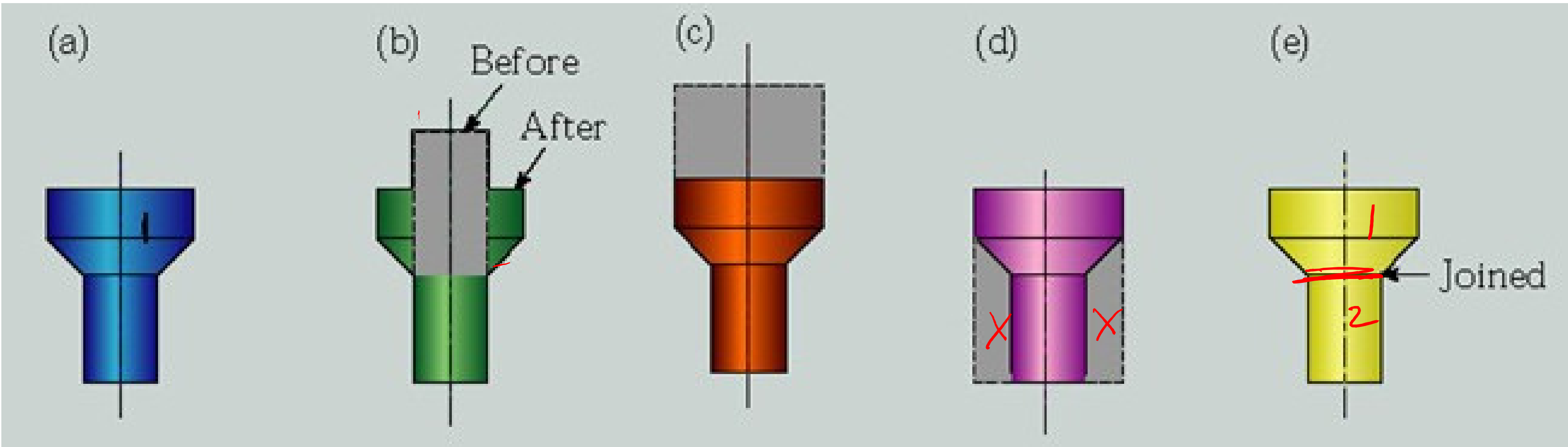
Different shapes and common method of production

Shape or feature	Production method[a]
Flat surfaces	Rolling, planing, broaching, milling, shaping, grinding
Parts with cavities	End milling, electrical-discharge machining, electrochemical machining, ultrasonic machining, blanking, casting, forging, extrusion, injection molding, metal injection molding
Parts with sharp features	Permanent-mold casting, machining, grinding, fabricating[b], powder metallurgy, coining
Thin hollow shapes	Slush casting, electroforming, fabricating, filament winding, blow molding, sheet forming, spinning
Tubular shapes	Extrusion, drawing, filament winding, roll forming, spinning, centrifugal casting
Tubular parts	Rubber forming, tube hydroforming, explosive forming, spinning, blow molding, sand casting, filament winding
Curvature on thin sheets	Stretch forming, peen forming, fabricating, thermoforming
Openings in thin sheets	Blanking, chemical blanking, photochemical blanking, laser machining
Cross sections	Drawing, extrusion, shaving, turning, centerless grinding, swaging, roll forming
Square edges	Fine blanking, machining, shaving, belt grinding
Small holes	Laser or electron-beam machining, electrical-discharge machining, electrochemical machining, chemical blanking
Surface textures	Knurling, wire brushing, grinding, belt grinding, shot blasting, etching, laser texturing, injection molding, compression molding
Detailed surface features	Coining, investment casting, permanent-mold casting, machining, injection molding, compression molding
Threaded parts	Thread cutting, thread rolling, thread grinding, injection molding
Very large parts	Casting, forging, fabricating, assembly
Very small parts	Investment casting, etching, powder metallurgy, nanofabrication, LIGA, micromachining

Note:
[a] Rapid prototyping operations can produce all of these features to some degree.
[b] 'Fabricating' refers to assembly from separately manufactured components.

Selection of Manufacturing Processes

- **Same part can be fabricated using different manufacturing processes**



casting
or
powder metallurgy

forging
or
upsetting

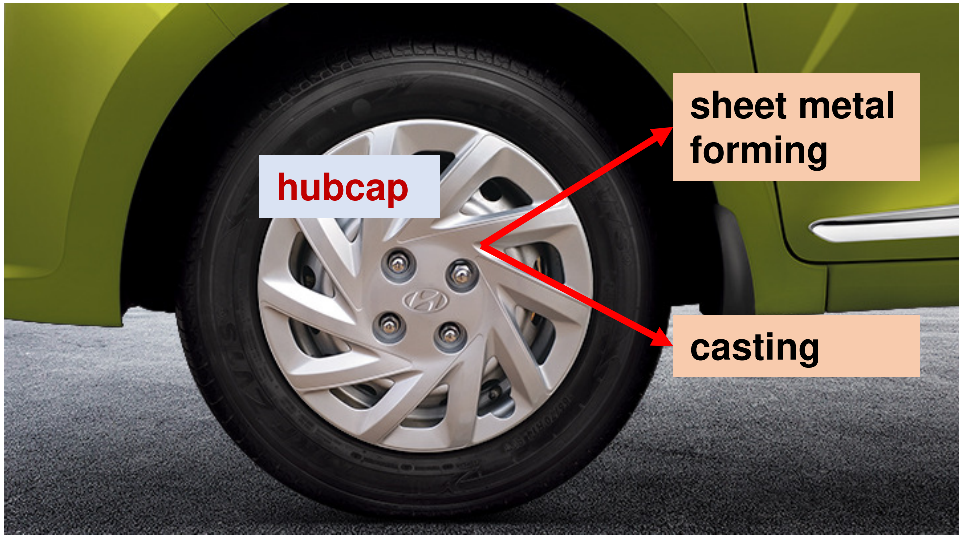
extrusion

machining

joining

Courtesy:
Manufacturing Processes for Engineering Materials, Kalpakjian and Schmid

Selection of Manufacturing Processes



www.hyundaimobisin.com

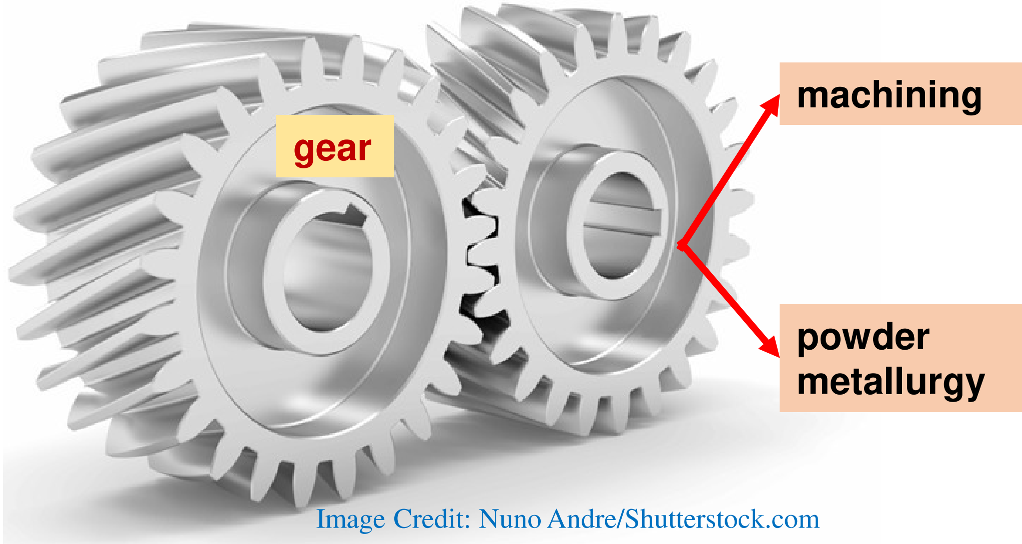
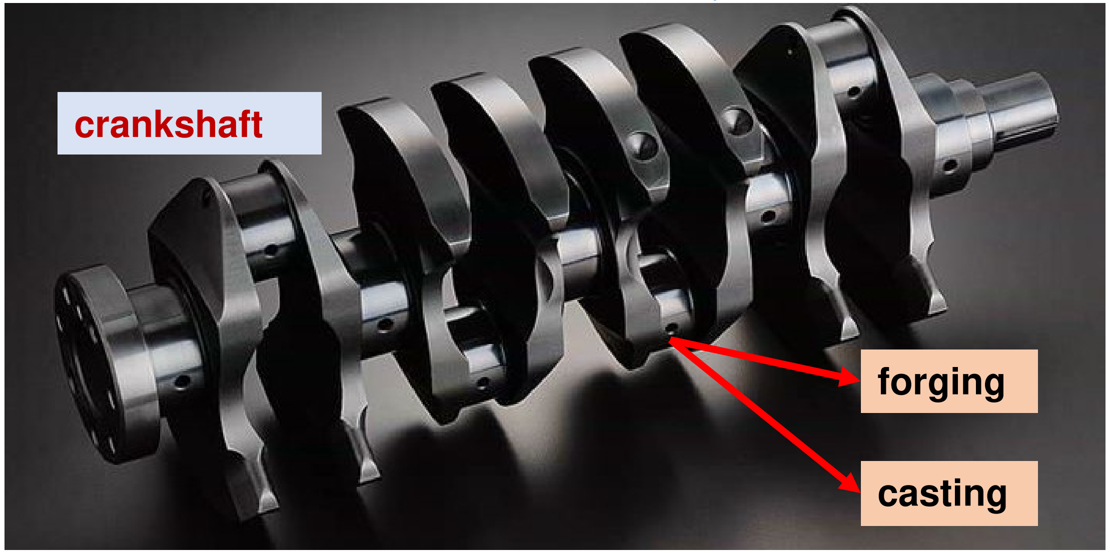


Image Credit: Nuno Andre/Shutterstock.com



www.carthrottle.com

www.desertcart.in

- Same product can be fabricated using different manufacturing processes

Number of parts in a product

- **Ballpoint pen** a dozen
- **Lawn mower** ~~50/1000~~ 300
- **Grand piano** ~~10000~~ 12000
- **Automobile** ~~100000~~ 15000
- **C-54 transport plane (used in Word War II)** 4M
- **Boeing 747-400** 6M

How old are manufacturing processes?

History of Materials and Manufacturing Processes

Period	Dates	Metals and casting	Various materials and composites	Forming and shaping	Joining	Tools, machining, and manufacturing systems
Egypt: ~ 3100 B.C. to ~ 300 B.C. Greece: ~ 1100 B.C. to ~ 146 B.C. Roman Empire: ~ 500 B.C. to 476 A.D.	Before 4000 B.C.	Gold, copper, meteoric iron	Earthenware, glazing, natural fibers	Hammering		Tools of stone, flint, wood, bone, ivory, composite tools
	4000–3000 B.C.	Copper casting, stone and metal molds, lost-wax process, silver, lead, tin, bronze		Stamping, jewelry	Soldering (Cu-Au, Cu-Pb, Pb-Sn)	Corundum (alumina, emery)
	3000–2000 B.C.	Bronze casting and drawing, gold leaf	Glass beads, potter's wheel, glass vessels	Wire by slitting sheet metal	Riveting, brazing	Hoe making, hammered axes, tools for ironmaking and carpentry
	2000–1000 B.C.	Wrought iron, brass				
	1000–1 B.C.	Cast iron, cast steel	Glass pressing and blowing	Stamping of coins	Forge welding of iron and steel, gluing	Improved chisels, saws, files, woodworking lathes
Middle Ages: ~ 476 to 1492 Renaissance: 14th to 16th centuries	1–1000 A.D.	Zinc, steel	Venetian glass	Armor, coining, forging, steel swords		Etching of armor
	1000–1500	Blast furnace, type metals, casting of bells, pewter	Crystal glass	Wire drawing, gold- and silversmith work		Sandpaper, windmill-driven saw
	1500–1600	Cast-iron cannon, tinplate	Cast plate glass, flint glass	Water power for metalworking, rolling mill for coinage strips		Hand lathe for wood
	1600–1700	Permanent-mold casting, brass from copper and metallic zinc	Porcelain	Rolling (lead, gold, silver), shape rolling (lead)		Boring, turning, screw-cutting lathe, drill press

Iron making middle east 1100 BC

production of steel Asia 600-800 AD

300 year after automated

Courtesy:
Manufacturing Processes for Engineering Materials, Kalpakjian and Schmid

History of Materials and Manufacturing Processes

Period	Dates	Metals and casting	Various materials and composites	Forming and shaping	Joining	Tools, machining, and manufacturing systems
Industrial Revolution: ~ 1750 to 1850	1700–1800	Malleable cast iron, crucible steel (iron bars and rods)		Extrusion (lead pipe), deep drawing, rolling		
WWI	1800–1900	Centrifugal casting, Bessemer process, electrolytic aluminum, nickel steel, babbitt, galvanized steel, powder metallurgy, open-hearth steel	Window glass from slit cylinder, light bulb, vulcanization, rubber processing, polyester, styrene, celluloid, rubber extrusion, molding	Steam hammer, steel rolling, seamless tube, steel-rail rolling, continuous rolling, electroplating		Shaping, milling, copying lathe for gunstocks, turret lathe, universal milling machine, vitrified grinding wheel
	1900–1920		Automatic bottle making, bakelite, borosilicate glass	Tube rolling, hot extrusion	Oxyacetylene; arc, electrical-resistance, and thermit welding	Geared lathe, automatic screw machine, hobbing, high-speed steel tools, aluminum oxide, and silicon carbide (synthetic)
	1920–1940	Die casting	Development of plastics, casting, molding, polyvinyl chloride, cellulose acetate, polyethylene, glass fibers	Tungsten wire from metal powder	Coated electrodes	Tungsten carbide, mass production, transfer machines
WWII	1940–1950	Lost-wax process for engineering parts	Acrylics, synthetic rubber, epoxies, photosensitive glass	Extrusion (steel), swaging, powder metals for engineering parts	Submerged arc welding	Phosphate conversion coatings, total quality control
	1950–1960	Ceramic mold, nodular iron, semiconductors, continuous casting	Acrylonitrile-butadiene-styrene, silicones, fluorocarbons, polyurethane, float glass, tempered glass, glass ceramics	Cold extrusion (steel), explosive forming, thermochemical processing	Gas metal arc, gas tungsten arc, and electroslag welding; explosion welding	Electrical and chemical machining, automatic control.

1750 industrial revolution

mid 1990 solid-state electronics & computer

Courtesy:
Manufacturing Processes for Engineering Materials, Kalpakjian and Schmid

History of Materials and Manufacturing Processes

Period	Dates	Metals and casting	Various materials and composites	Forming and shaping	Joining	Tools, machining, and manufacturing systems
	1960–1970	Squeeze casting, single-crystal turbine blades	Acetals, polycarbonate, cold forming of plastics, reinforced plastics, filament winding	Hydroforming, hydrostatic extrusion, electroforming	Plasma-arc and electron-beam welding, adhesive bonding	Titanium carbide, synthetic diamond, numerical control, integrated circuit chip
Space Age	1970–1990	Compacted graphite, vacuum casting, organically-bonded sand, automation of molding and pouring, rapid solidification, metal-matrix composites, semi-solid metalworking, amorphous metals, shape-memory alloys	Adhesives, composite materials, semiconductors, optical fibers, structural ceramics, ceramic-matrix composites, biodegradable plastics, electrically-conducting polymers	Precision forging, isothermal forging, superplastic forming, dies made by computer-aided design and manufacturing, net-shape forging and forming, computer simulation	Laser beam, diffusion bonding (also combined with superplastic forming), surface-mount soldering	Cubic boron nitride, coated tools, diamond turning, ultraprecision machining, computer-integrated manufacturing, industrial robots, machining and turning centers, flexible manufacturing systems, sensor technology, automated inspection, computer simulation and optimization
Information Age	1990–2000	Rheocasting, computer-aided design of molds and dies, rapid tooling	Nanophase materials, metal foams, high-temperature superconductors, machinable ceramics, diamond-like carbon	Additive manufacturing, rapid tooling, environmentally-friendly metalworking fluids	Friction stir welding, lead-free solders, laser butt-welded (tailored) sheet-metal blanks	Micro- and nanofabrication, LIGA, dry etching, linear motor drives, artificial neural networks, Six Sigma
	2000–2010s	TRIP and TWIP steels	Carbon nanotubes, graphene	Single point incremental forming, hot stamping, electrically assisted forming	Linear friction welding	Digital manufacturing, three-dimensional computer chips, blue-arc machining, soft lithography, flexible electronics

Courtesy:
Manufacturing Processes for Engineering Materials, Kalpakjian and Schmid

History of Metallurgy in India

The forging of wrought iron seems to have reached its zenith in India in the first millennium AD. The earliest large forging is the famous iron pillar at New Delhi dated by inscription to the **Gupta period of the 3rd century AD** at a **height of over 7 m** and **weight of about 6 tons**. The pillar is believed to have been **made by forging together a series of disc-shaped iron blooms.**

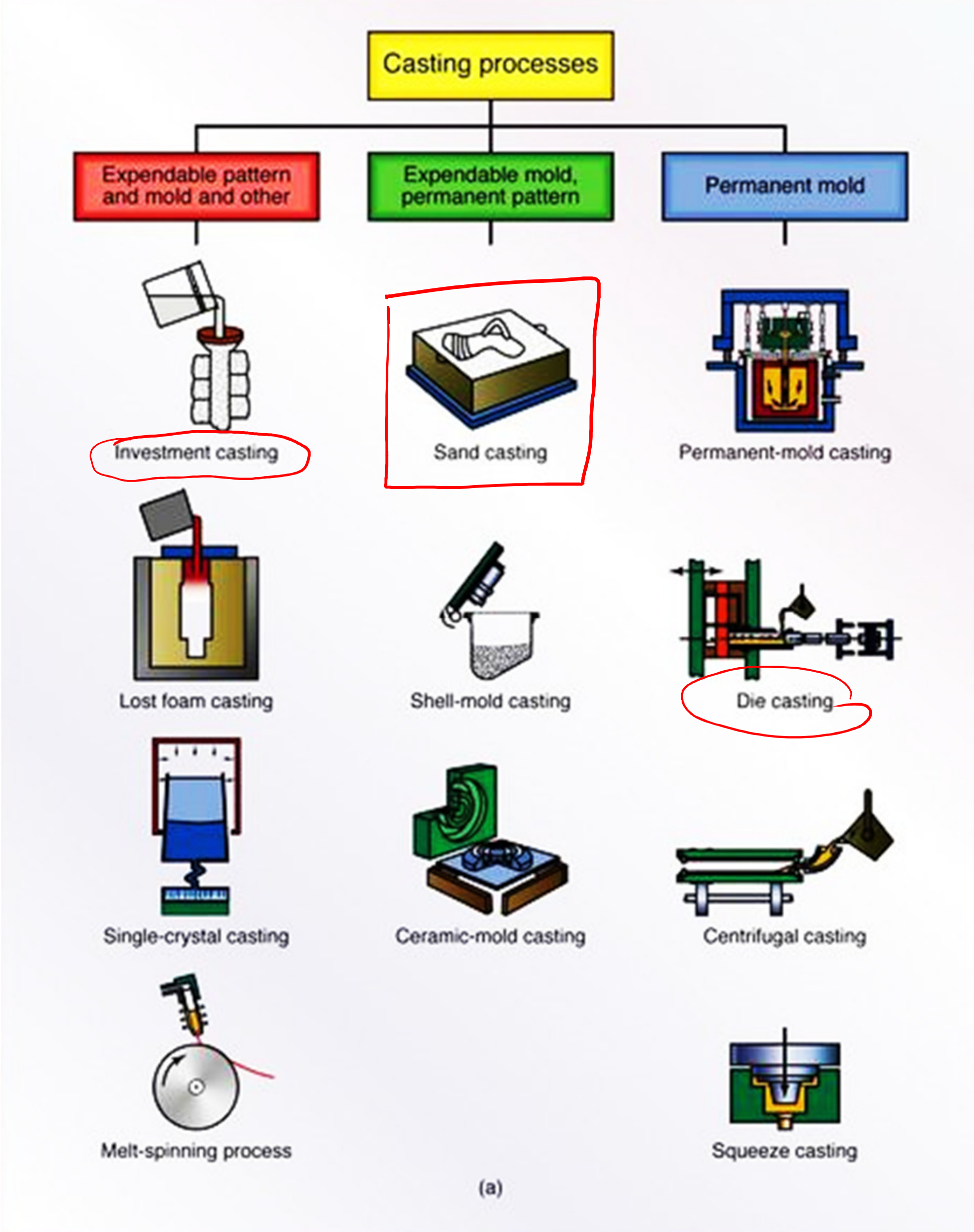
Apart from the dimensions another remarkable aspect of the iron pillar is the **absence of corrosion** which has been linked to the composition, the high purity of the wrought iron and the phosphorus content and the distribution of slag.

The height of the pillar, from the top to the bottom of its base, is 7.21 m (23 ft 8 in), 1.12 m (3 ft 8 in) of which is below ground. It is estimated to weigh more than six tonnes

Courtesy: Wikipedia

Courtesy: METALLURGICAL HERITAGE OF INDIA
S. Srinivasan and S. Ranganathan

Different casting processes



mold

pattern

expendable

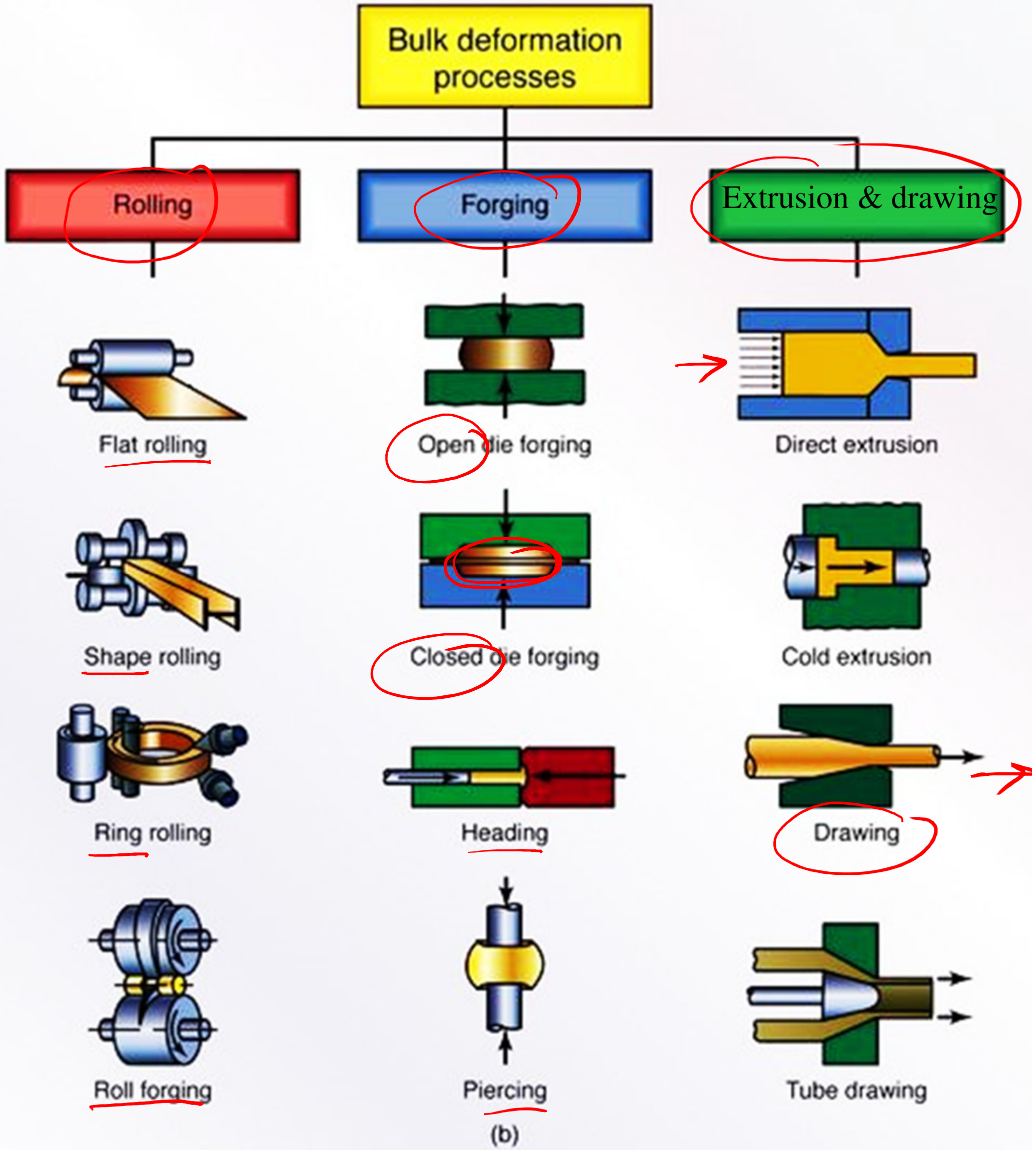
Courtesy:
Manufacturing Engineering and Technology, Kalpakjian and Schmid

Different bulk-deformation processes

Forming

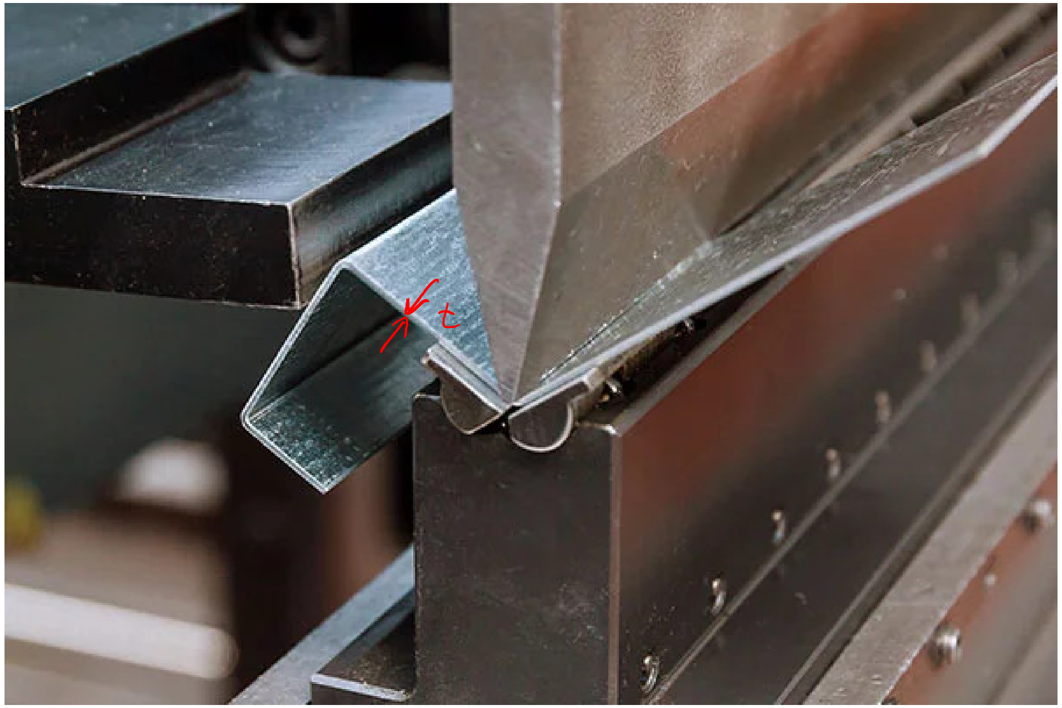
Hot rolling

www.montanstahl.com



Courtesy:
Manufacturing Engineering and Technology, Kalpakjian and Schmid

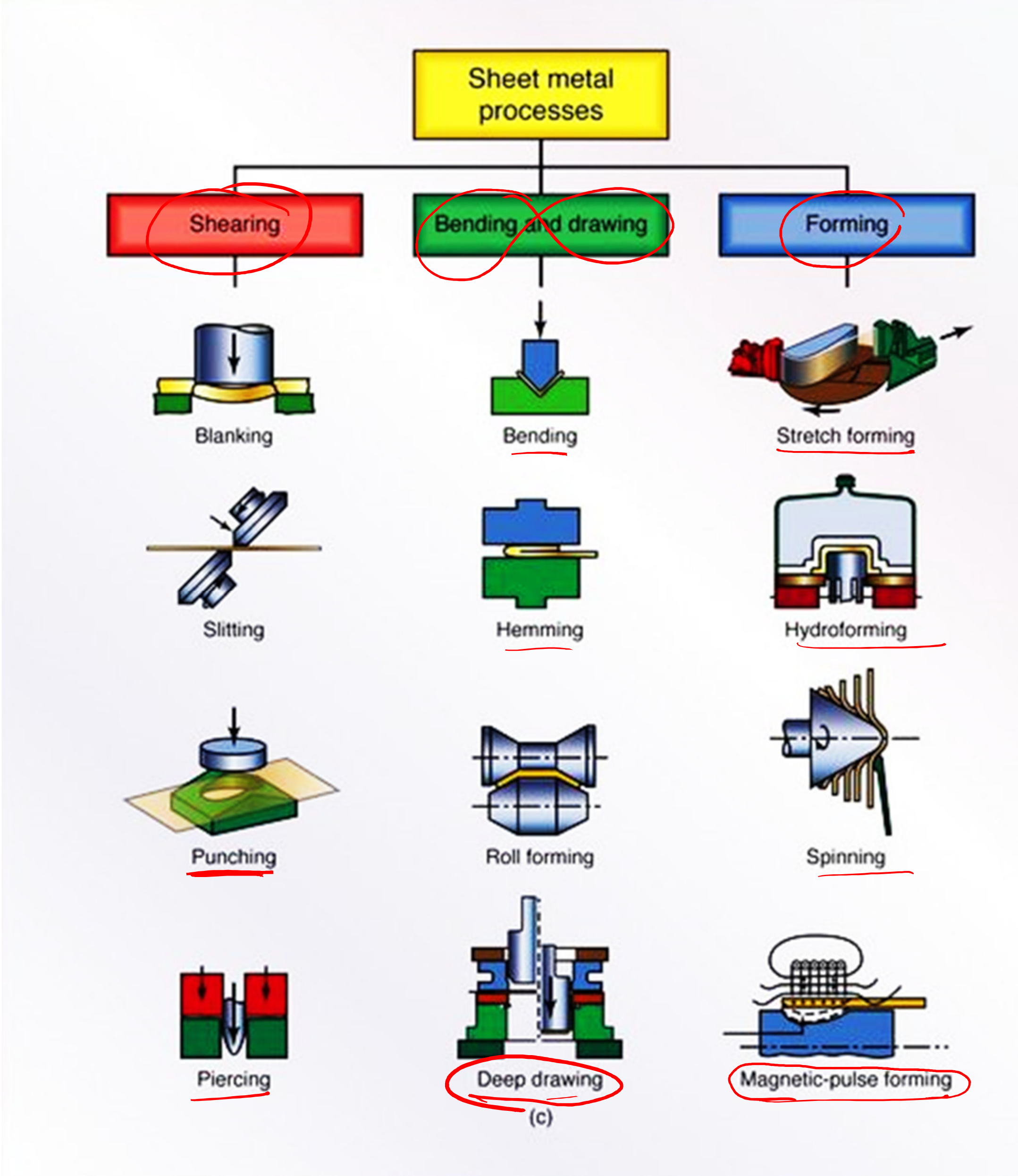
Different Sheet-metal forming processes



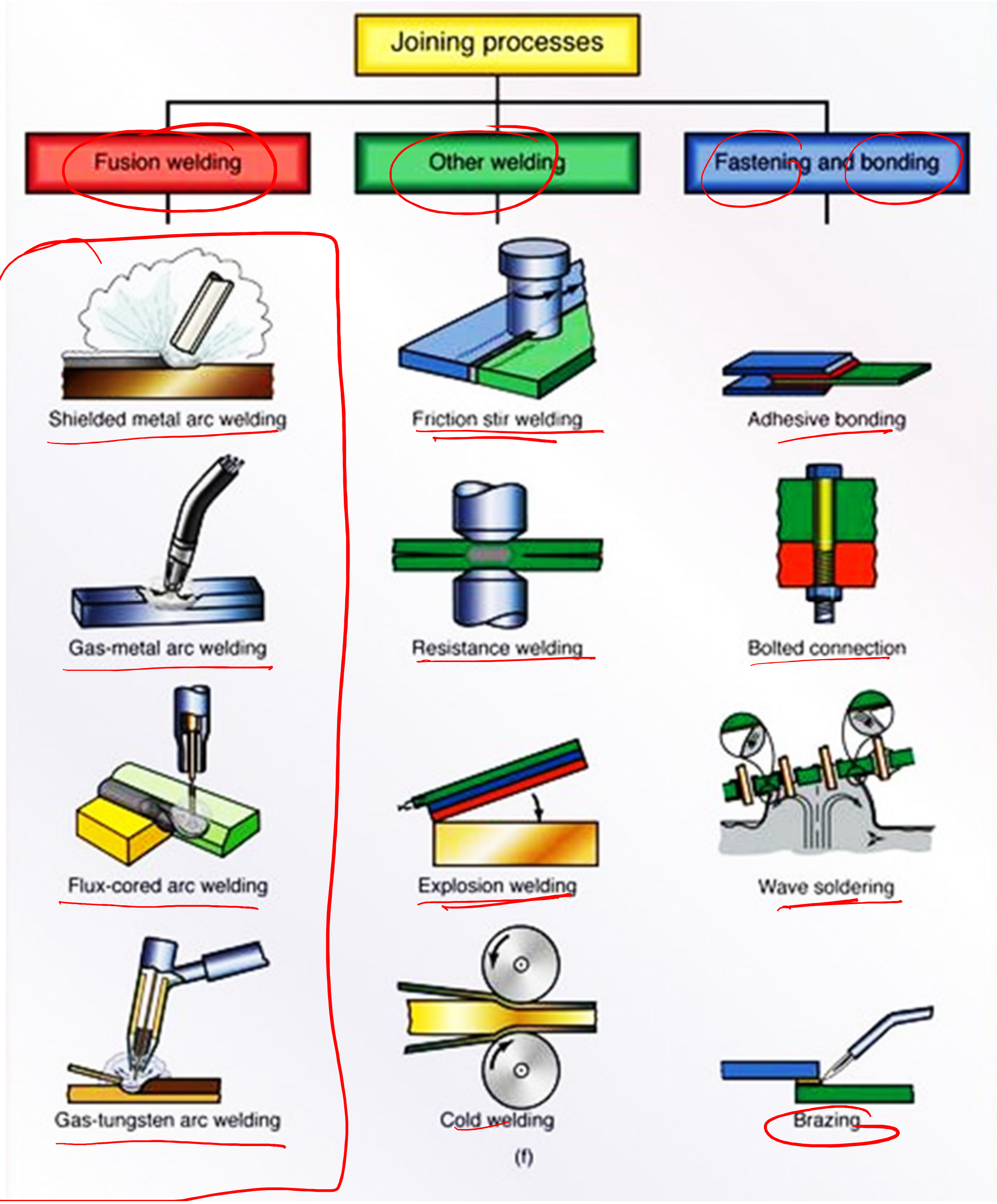
Sheet metal forming

www.lsengineering.co.uk

Courtesy:
Manufacturing Engineering and Technology,
Kalpakjian and Schmid



Different joining processes

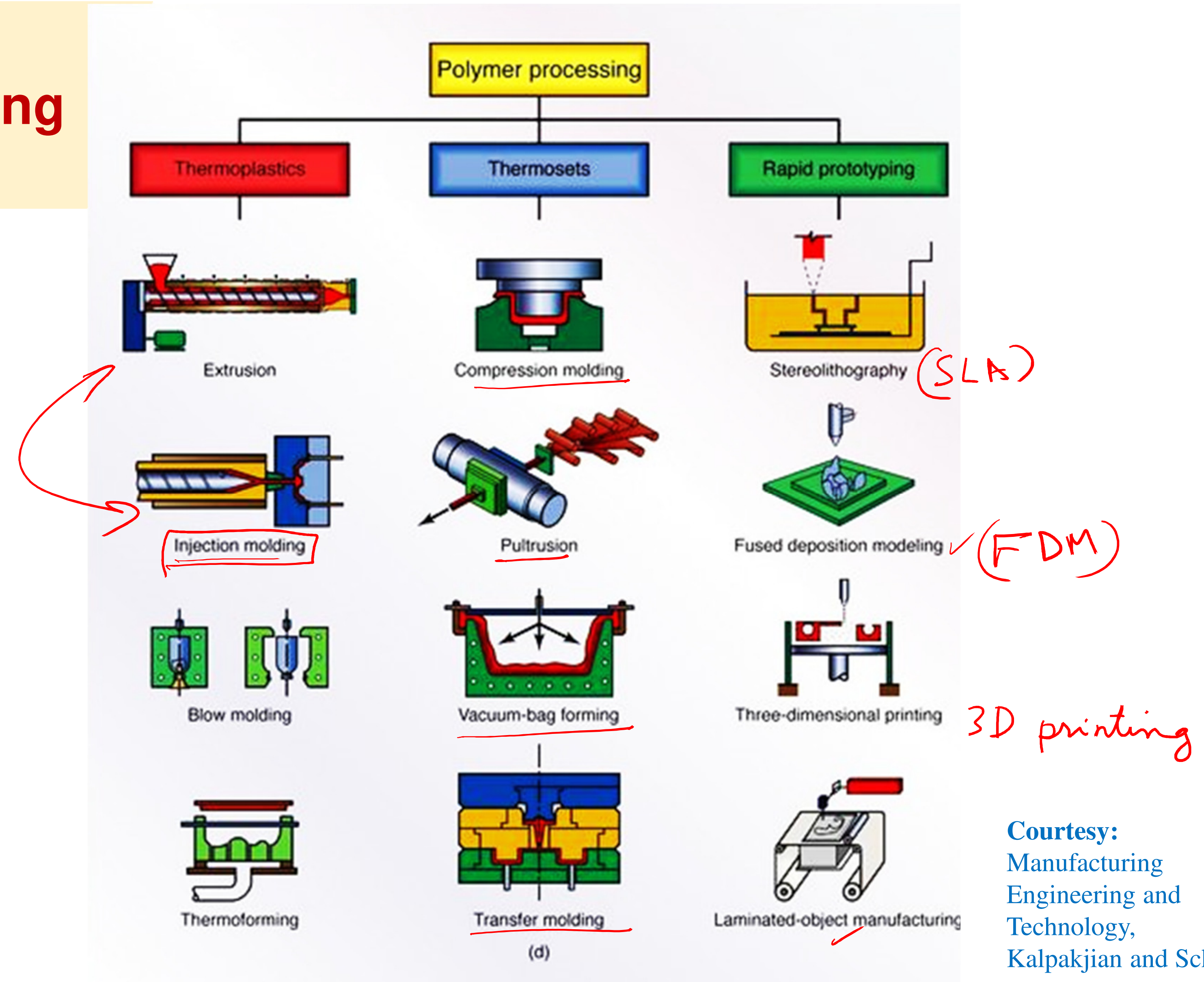


Brazing

Soldering

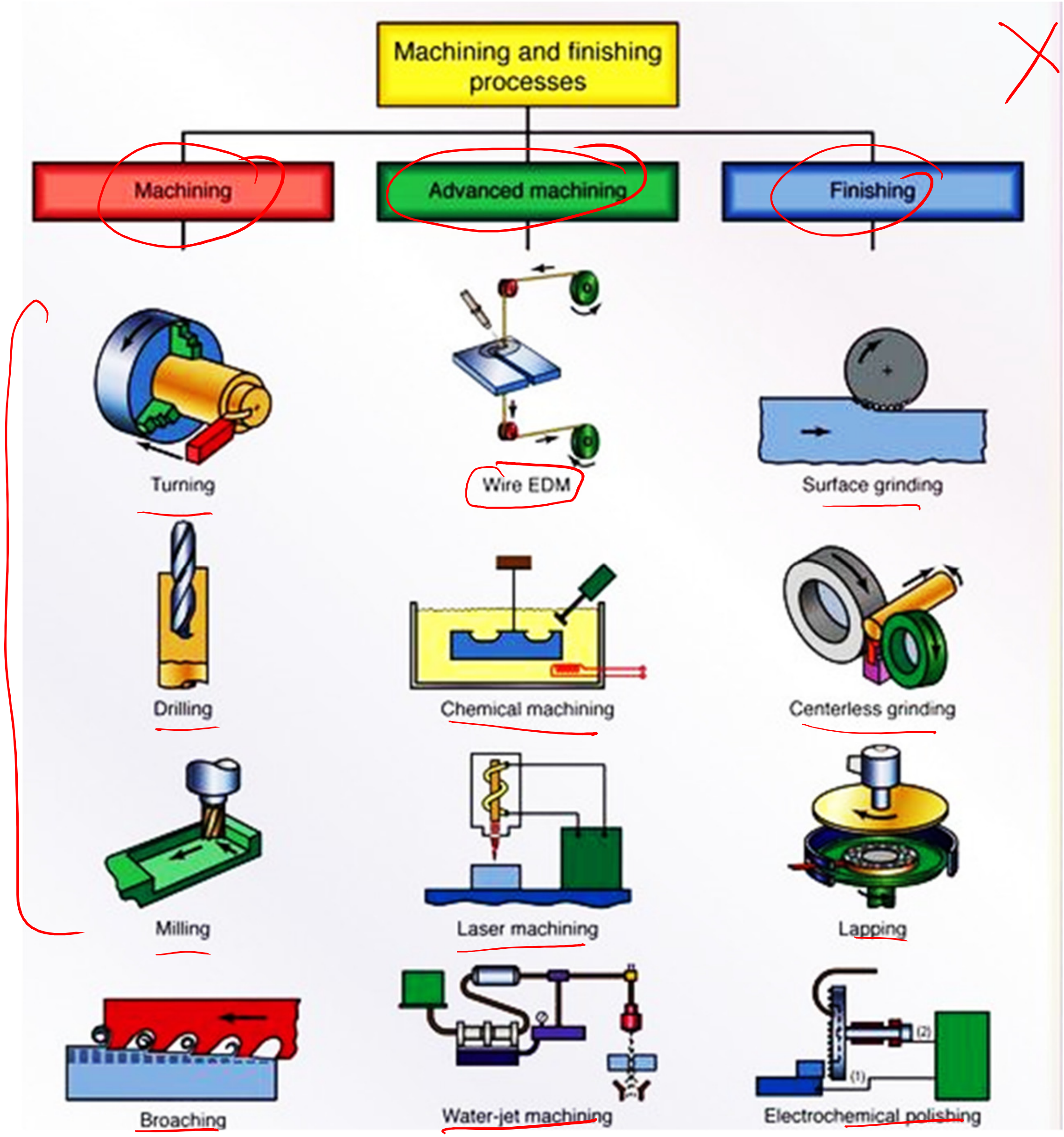
Courtesy:
Manufacturing Engineering and Technology, Kalpakjian and Schmid

Different Polymer-processing techniques



Courtesy: Manufacturing Engineering and Technology, Kalpakjian and Schmid

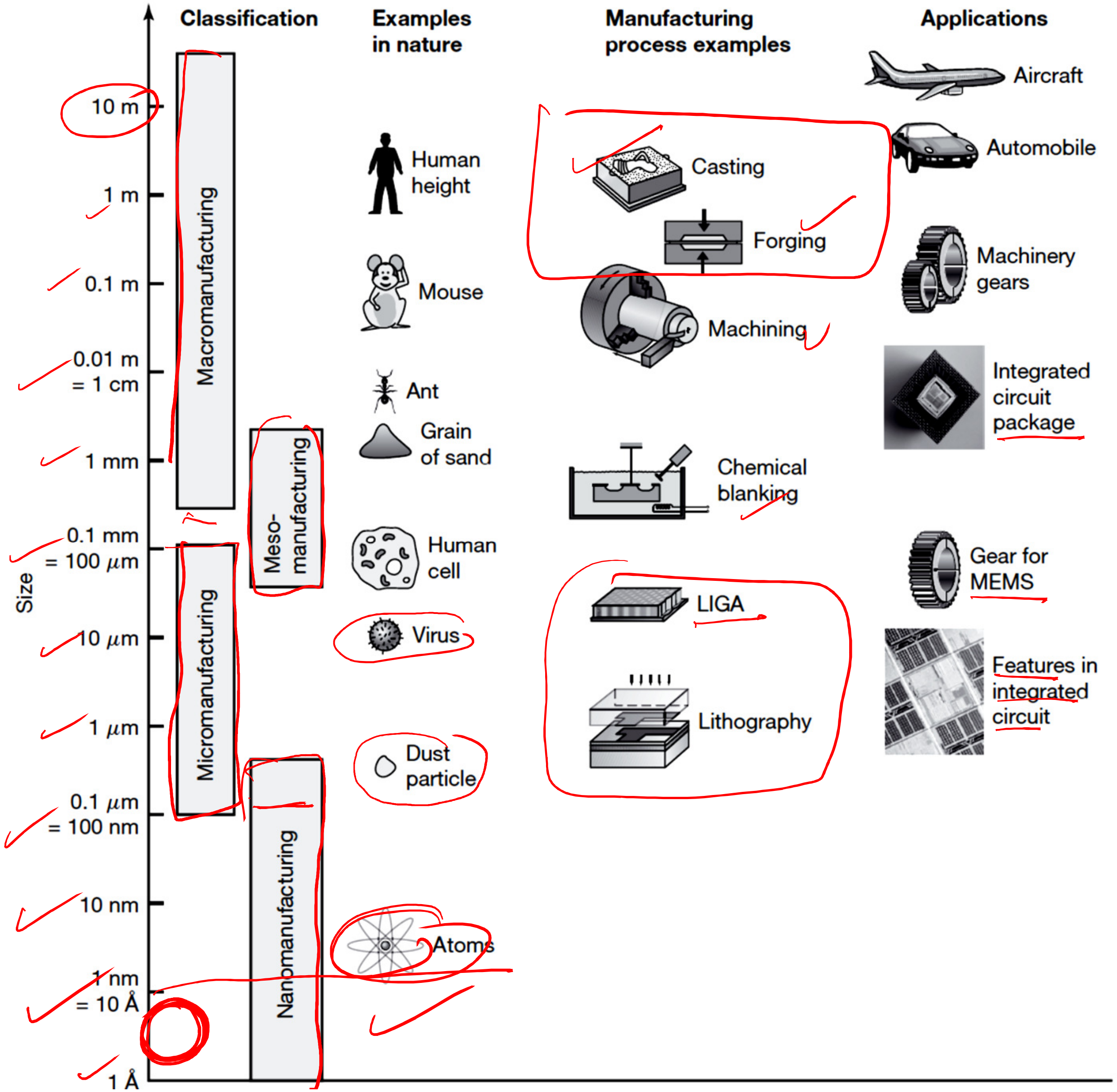
Different machining and finishing processes



Courtesy:
Manufacturing Engineering and Technology, Kalpakjian and Schmid

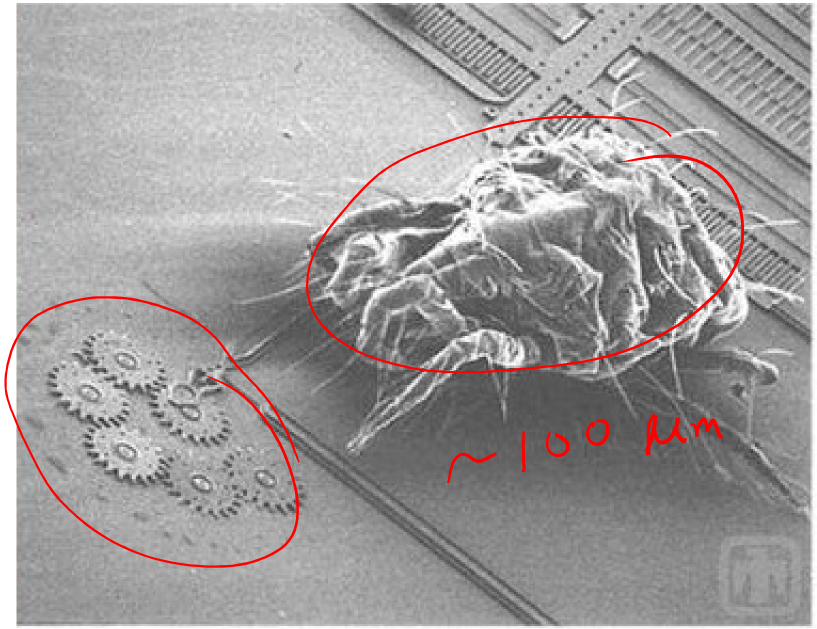
Length-scale of manufacturing processes

- **Macromanufacturing**
- **Micromanufacturing**
- **Nanomanufacturing**

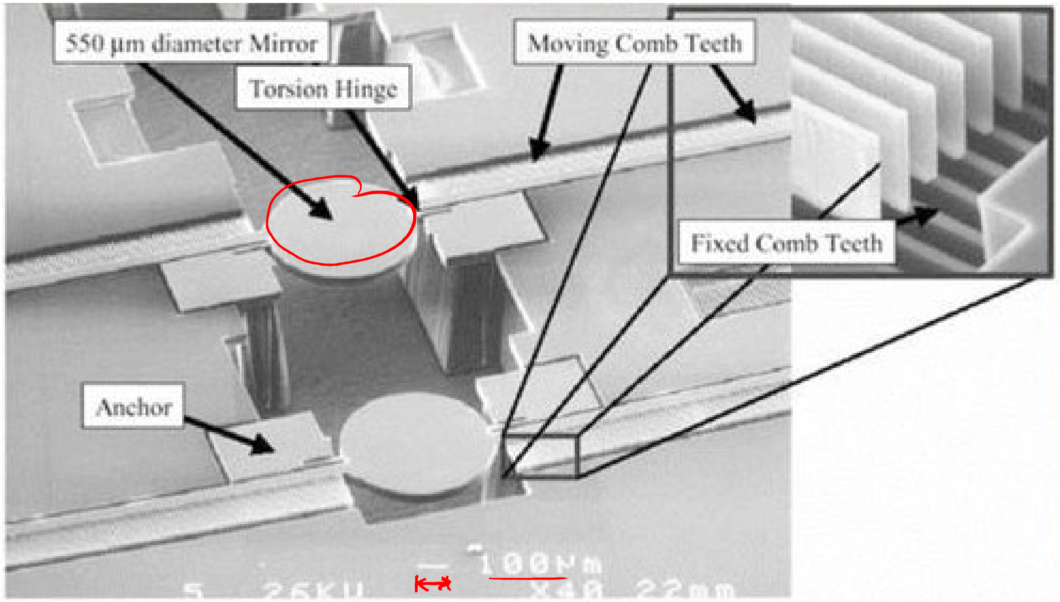


Courtesy:
Manufacturing Processes for Engineering Materials, Kalpakjian and Schmid

Microscopic components



(a) Microscopic gears with dust mite.
Source: Courtesy Sandia National Laboratory;



(b) A movable micro-mirror component of a light sensor.
Source: Courtesy of Richard Mueller, University of California at Berkeley.

Courtesy:
Manufacturing Engineering and Technology,
Kalpakjian and Schmid

Manufacturing Importance

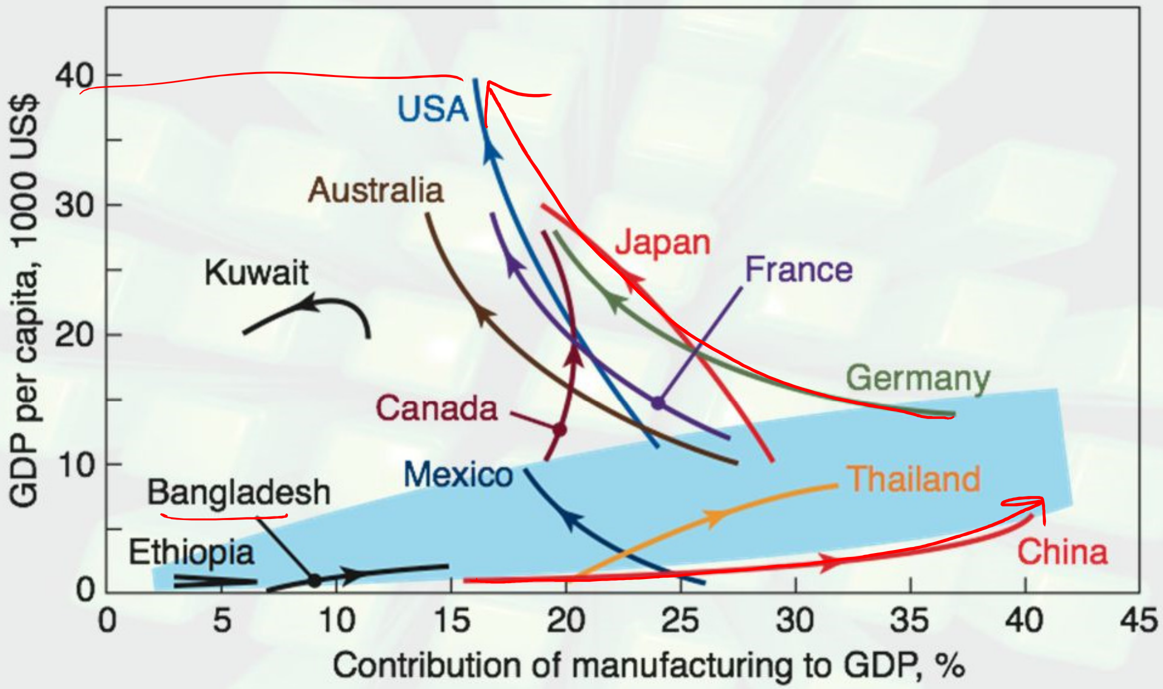


FIGURE 1.2 Importance of manufacturing to national economies. The trends shown are from 1982 until 2006. *Source:* After J.A. Schey with data from the *World Development Report*, World Bank, various years.

Manufacturing Processes for Engineering Materials, 5th ed.
Kalpakjian • Schmid

ISBN No. 0-13-227271-7

- Kuwait and Mexico- High natural resources oil
- Other countries need to generate wealth
- Even if absolute level of manufacturing increases, % GDP may not increase if the economy grows

- Countries with largest GDP growth have produced high value-added products
- E.g., automobiles, airplanes, medical devices, computers, electronics, and machinery

- Countries with lower labour rates have labour intensive products
- E.g., clothing, toys, hand-held tools

- Such labour-intensive manufacturing is associated with traditional curve shown as a shaded area.

Range of Materials & Processes in a Tractor

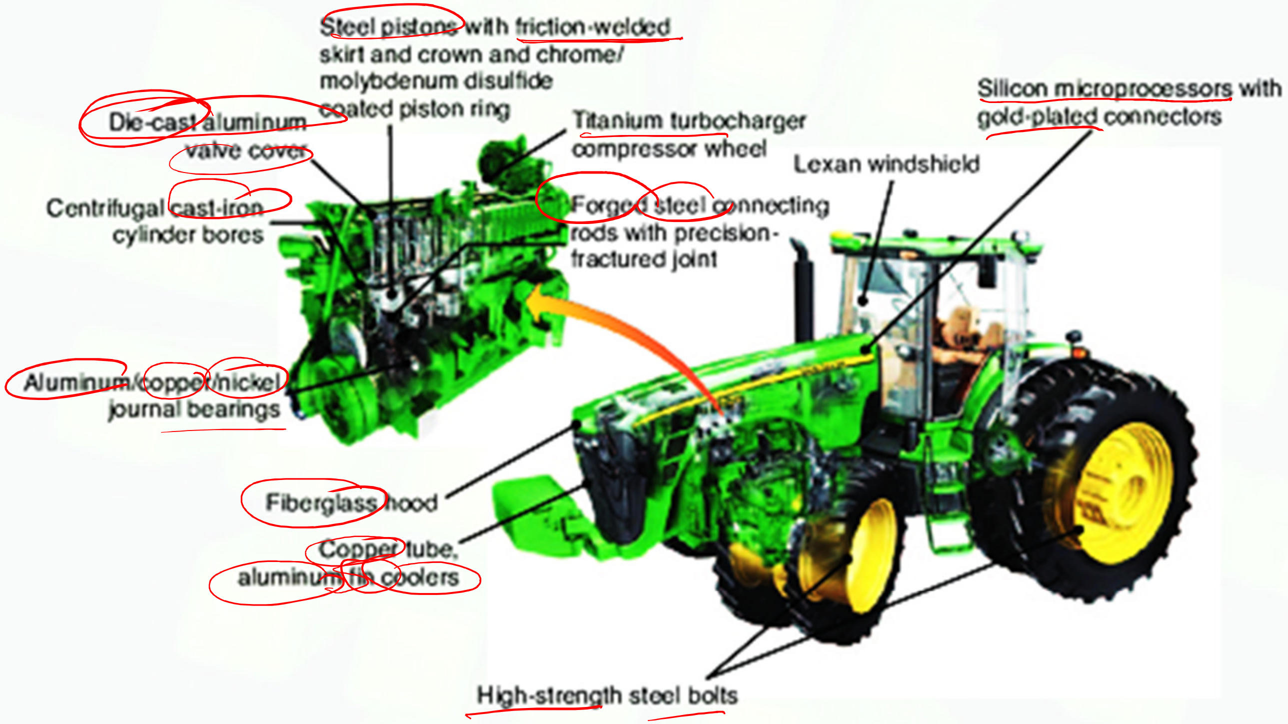


FIGURE 1.1 Model 8430 tractor, with detailed illustration of its diesel engine, showing the variety of materials and processes incorporated. *Source:* Courtesy of John Deere Company.

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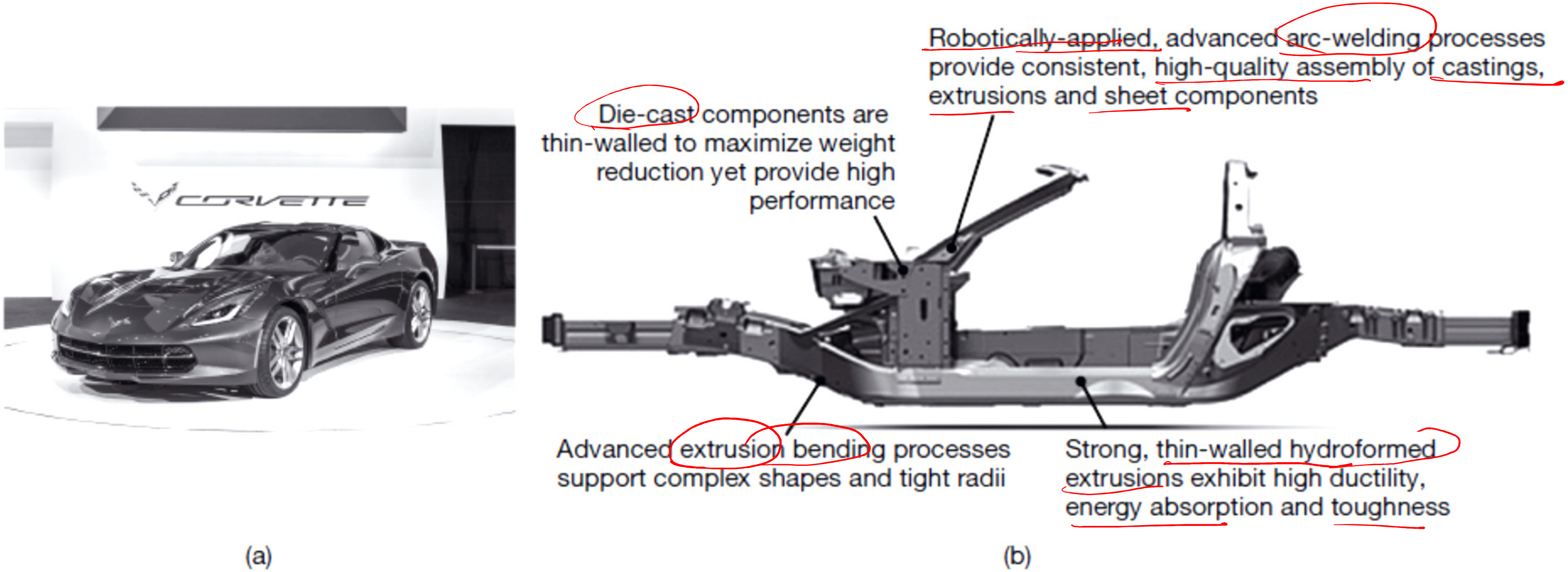
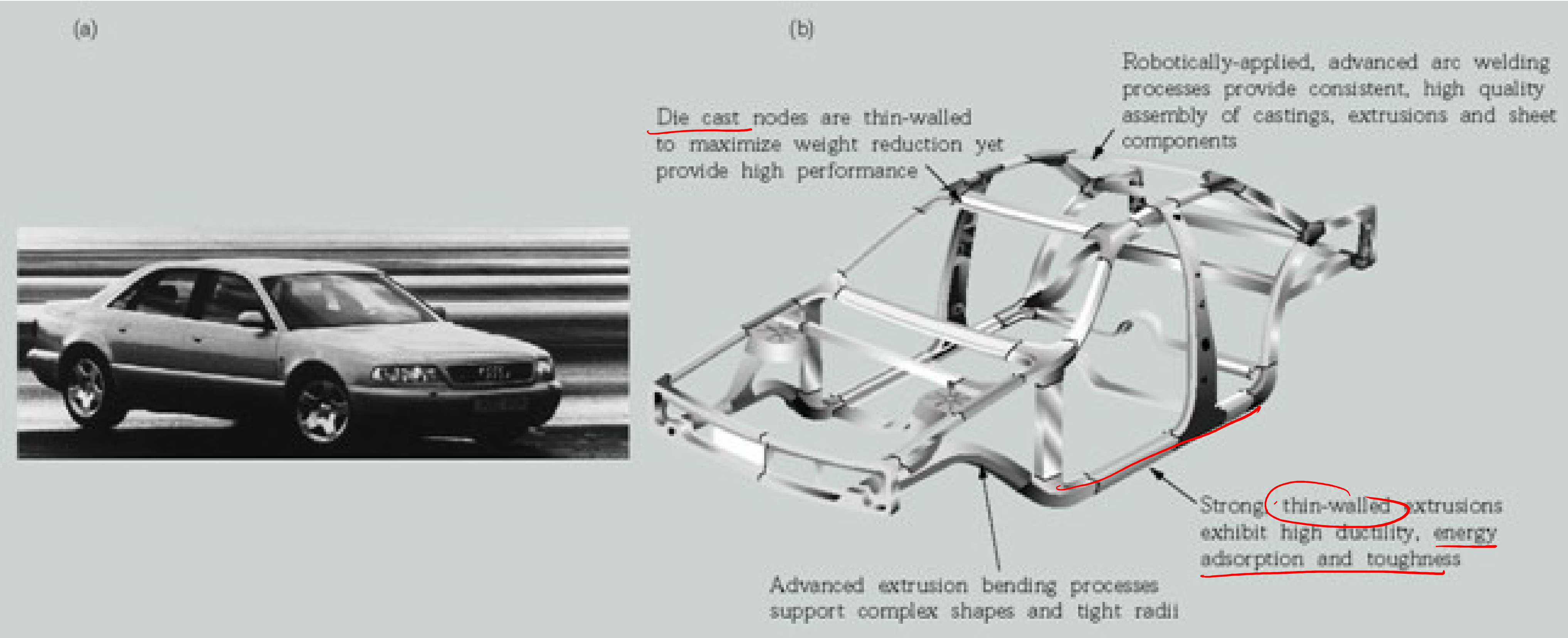


FIGURE 1.6 (a) The C7 Corvette sports car, using an all-aluminum chassis which is 45 kg lighter and 57% stiffer than the C6 Corvette; (b) The aluminum body structure, showing various components made by extrusion, sheet forming, and casting processes. *Source:* Courtesy of General Motors Corp.

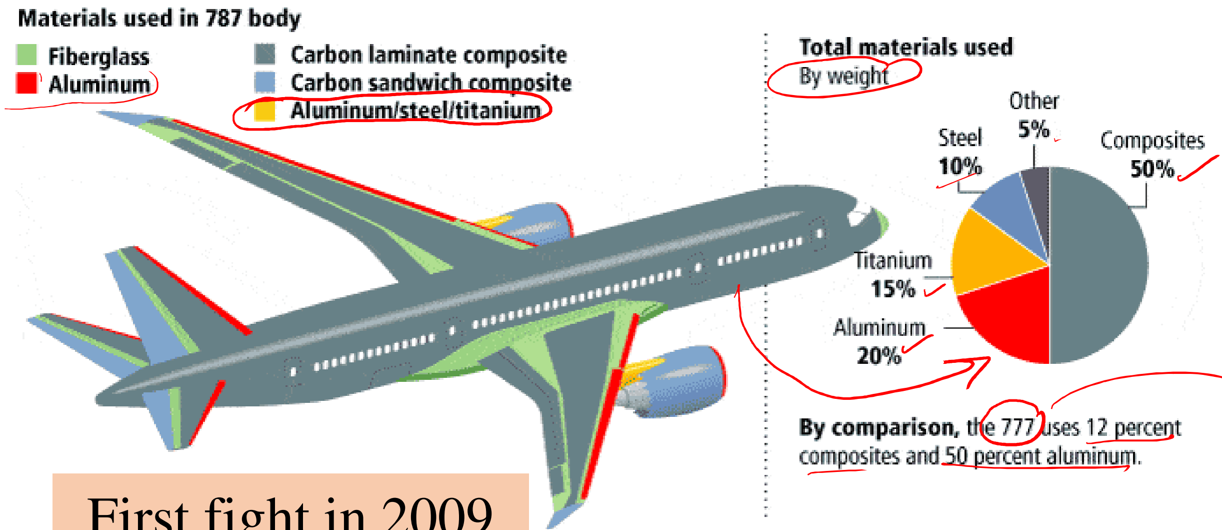
Courtesy:
Manufacturing Processes for Engineering Materials, Kalpakjian and Schmid


(a)
(b)
Robotically-applied, advanced arc welding processes provide consistent, high quality assembly of castings, extrusions and sheet components
Die cast nodes are thin-walled to maximize weight reduction yet provide high performance
Strong thin-walled extrusions exhibit high ductility, energy adsorption and toughness
Advanced extrusion bending processes support complex shapes and tight radii

Materials for Manufacturing

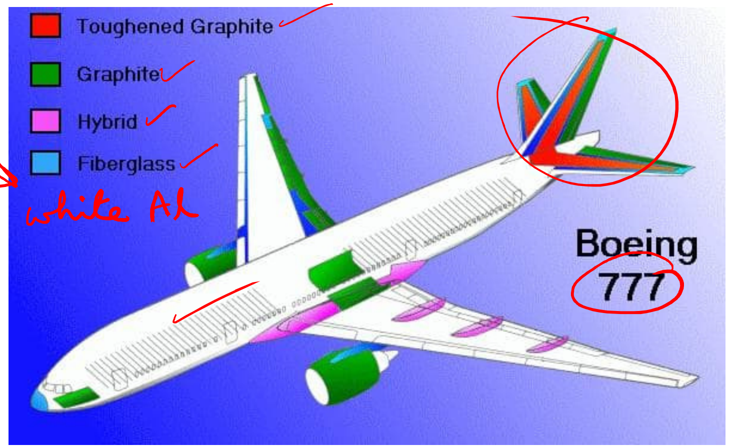
Materials used in Boeing 787

797
↳ 2025



First fight in 2009

www.boeing.com



white Al

First fight in 1994

www.aerocorner.com

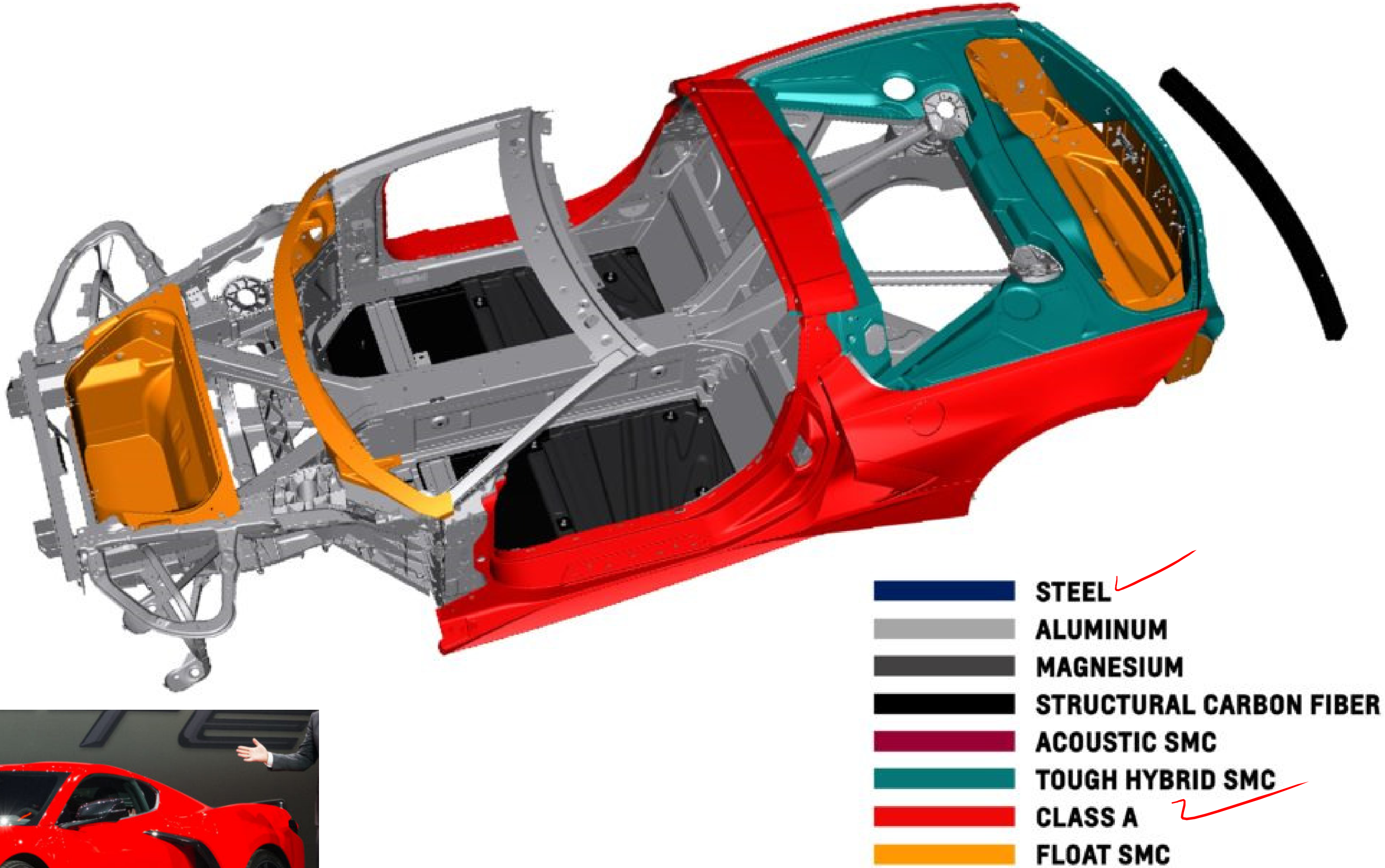
- Boeing 787 makes greater use of composite materials .
- weight savings of 20 percent compared to more conventional Al designs.
- Al is sensitive to tension loads but handles compression very well.
- composites are not as efficient under compression but are excellent under tension.
- Use of composites, especially in the highly tension-loaded environment of the fuselage, greatly reduces maintenance due to fatigue.

composite over Al

- Environmental considerations indicate aluminum is a poor choice, titanium is an excellent low-maintenance design solution.
- Titanium can withstand comparable loads better than aluminum, has minimal fatigue concerns, and is highly resistant to corrosion.

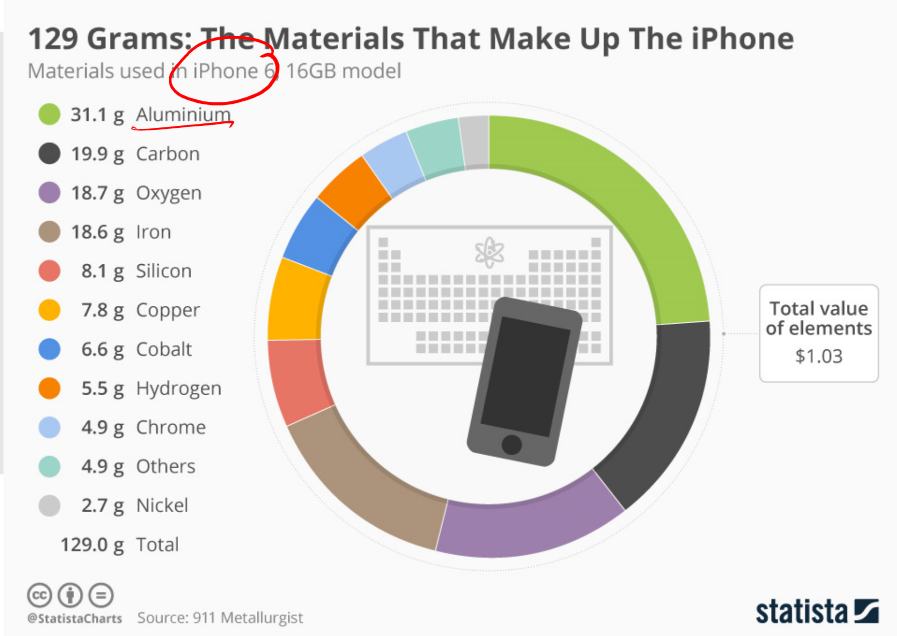
Ti over Al

2020 Chevrolet Corvette Stingray



www.repairerdrivennews.com

Materials for Iphone

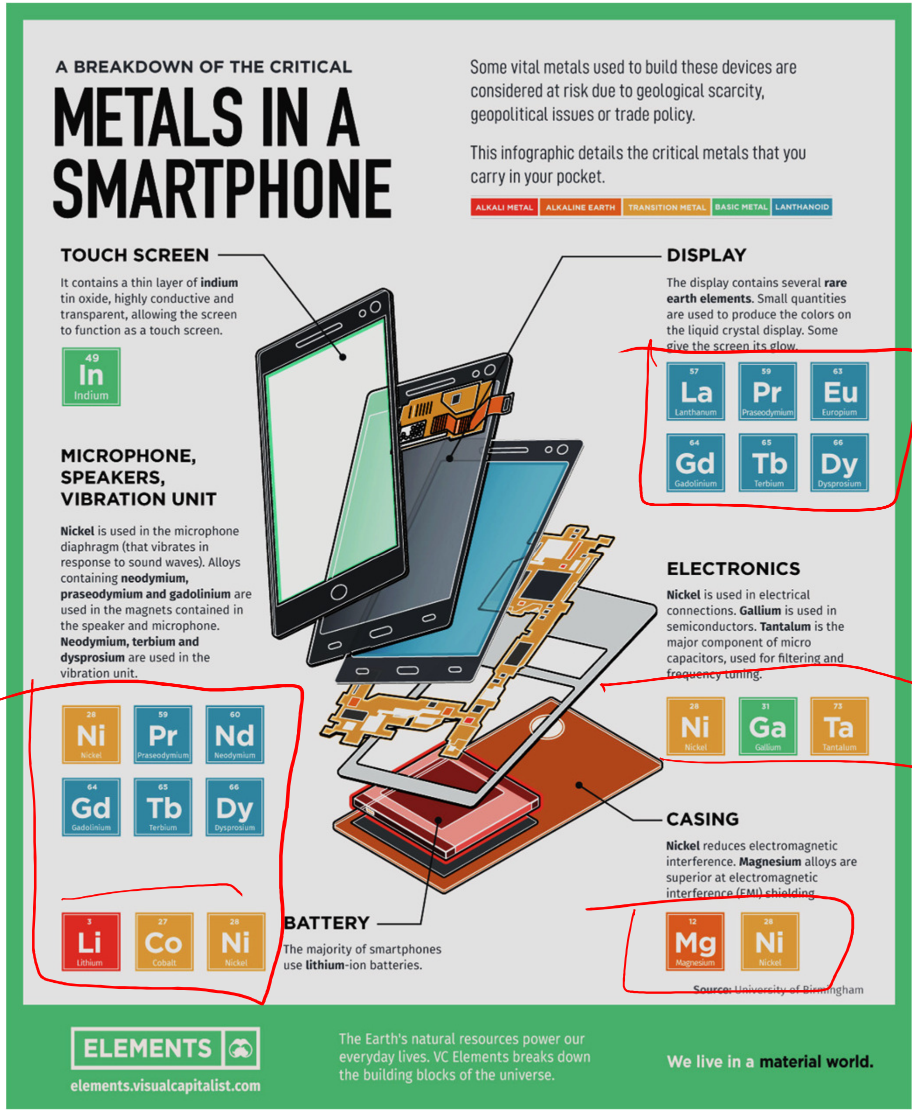


The Manufacturing Journey of iPhone by ÖZGÜN, 2018
https://www.mechead.com/manufacturing-journey-iphone-factory-floor-retail-store/

Material Selection

As a base material, Apple has been using 6000-7000 Aluminium series metal for the iPhone models for a long while. 6000 series aluminium contains added manganese and silicon. This combination of elements allows the alloy to be solution heat treated which improves the alloys strength. 7000 series aluminium is alloyed with zinc and can be precipitation hardened to provide the highest strength of all commercially available aluminium's.

Other Materials used in Smart Phones



Materials processing technologies

Materials processing - manufacture of raw-**materials** into finished goods
Industrial processes - various mechanical or chemical procedures, and produce large quantities or batches.

Raw materials - either extracted from minerals or produced from basic chemicals or natural substances.
Metallic raw materials - crude ore is processed to increase the concentration of the desired metal
It involves crushing, roasting, magnetic separation, flotation, and leaching.
Additional processes - smelting and alloying are used to produce the metal that is to be fabricated into parts that are eventually assembled into a product

Manufacturing Characteristics of Alloys

General Manufacturing Characteristics of Various Alloys			
Alloy	Castability	Weldability	Machinability
Aluminum	E	F	E-G
Copper	G-F	F	G-F
Gray cast iron	E	D	G
White cast iron	G	VP	VP
Nickel	F	F	F
Steels	F	E	F
Zinc	E	D	E

Note: E, excellent; G, good; F, fair; D, difficult; VP, very poor.

Courtesy:
Manufacturing Engineering and Technology,
Kalpakjian and Schmid

Materials processing technologies

Iron – Found as mineral compound, such as ores

Iron ores – iron oxides + impurities

Chemical reducing reactions is used to extract metallic iron

Ore + limestone + coke + air – reacted in furnace

Oxides are reduced, but other elements are mixed with iron such as

Carbon – 3 – 4.5%
Manganese – 0.15 – 2.5%
Phosphorus – 0.1 – 2 5
Silicon – 1 – 3 %
Sulfur – 0.05 – 0.1 %

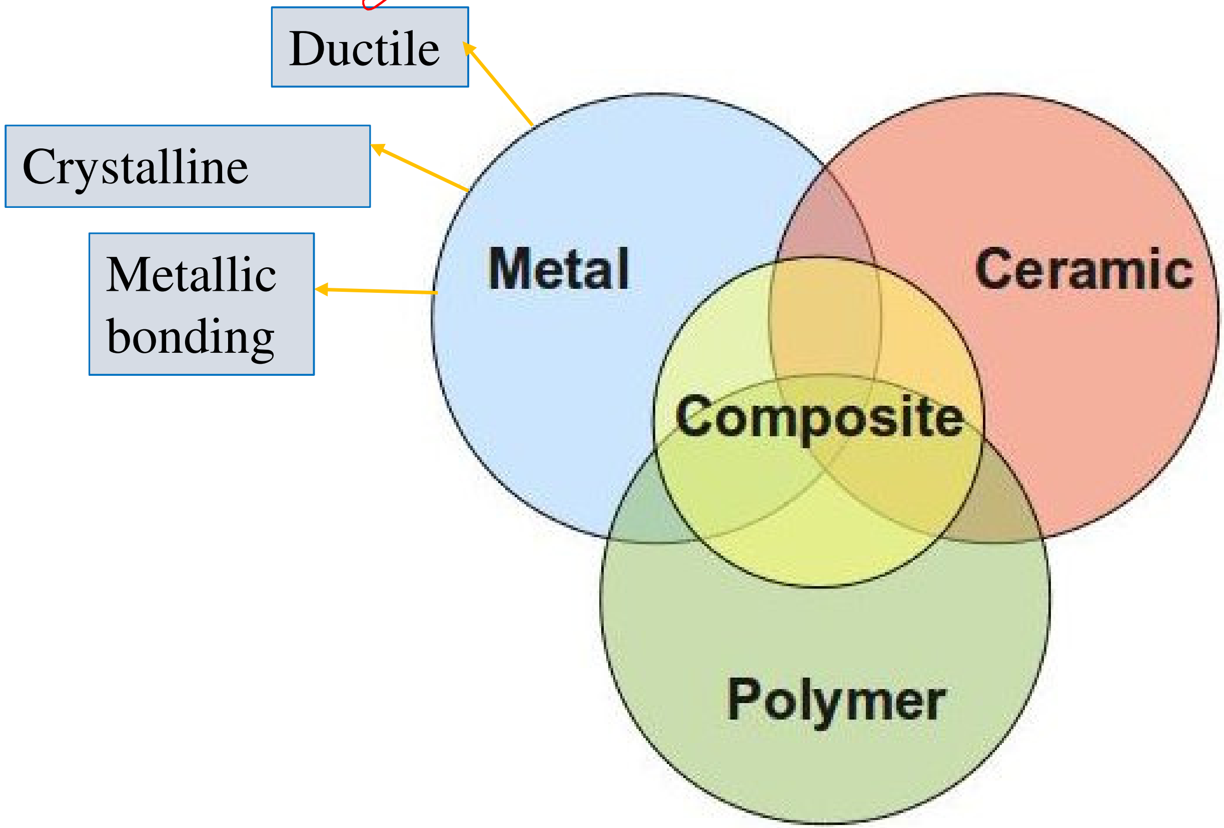
Pig iron

Materials processing technologies

Pig iron is cast into shape – which is called cast iron
Other impurities forms the slag

Steel: made by an oxidation process that decrease the amount of carbon, Mn, P, S from molten pig iron and steel scrap

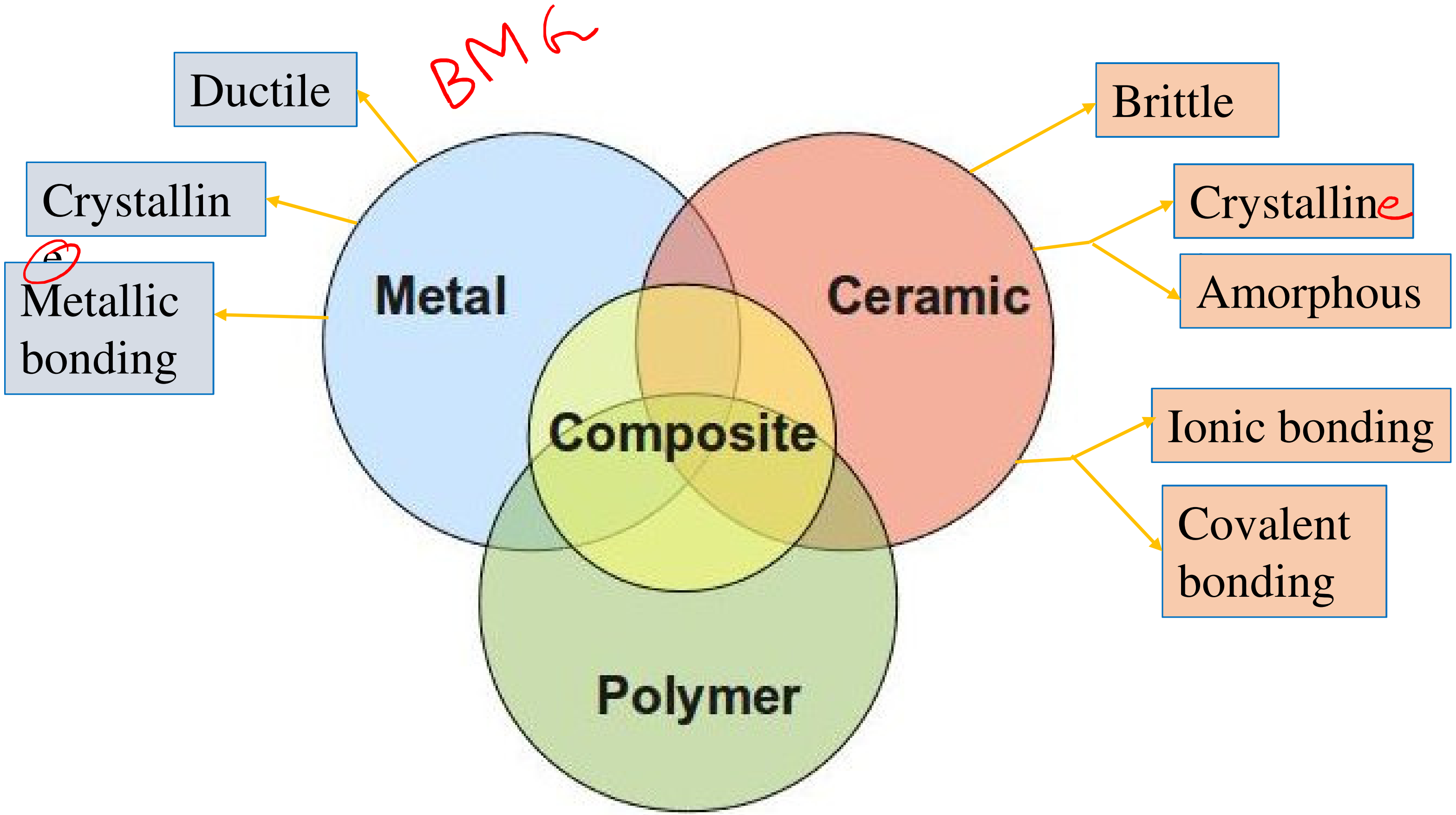
Classification of Materials-1



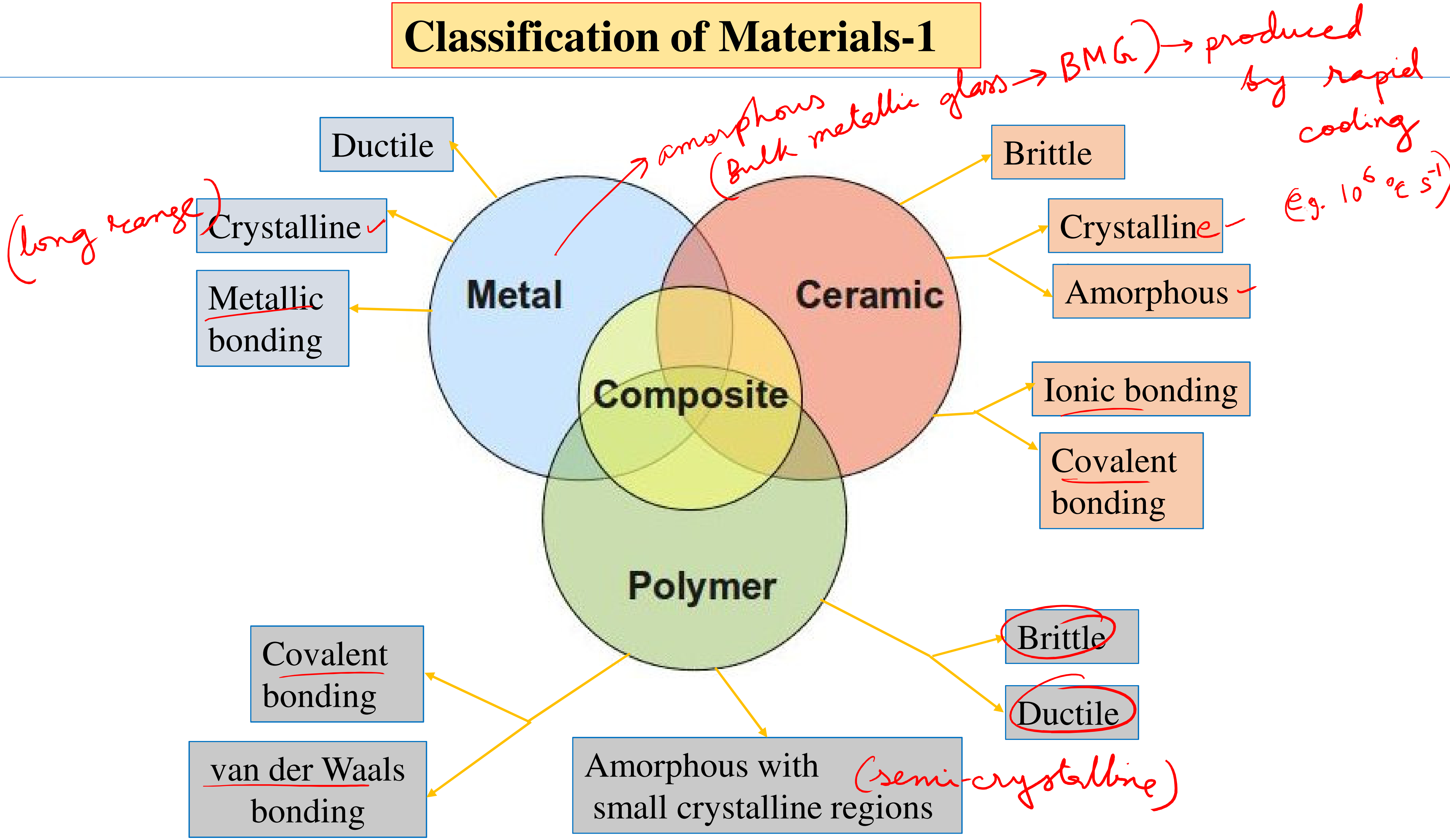
2 → ductile
→ brittle

3 → crystalline
→ amorphous

Classification of Materials-1

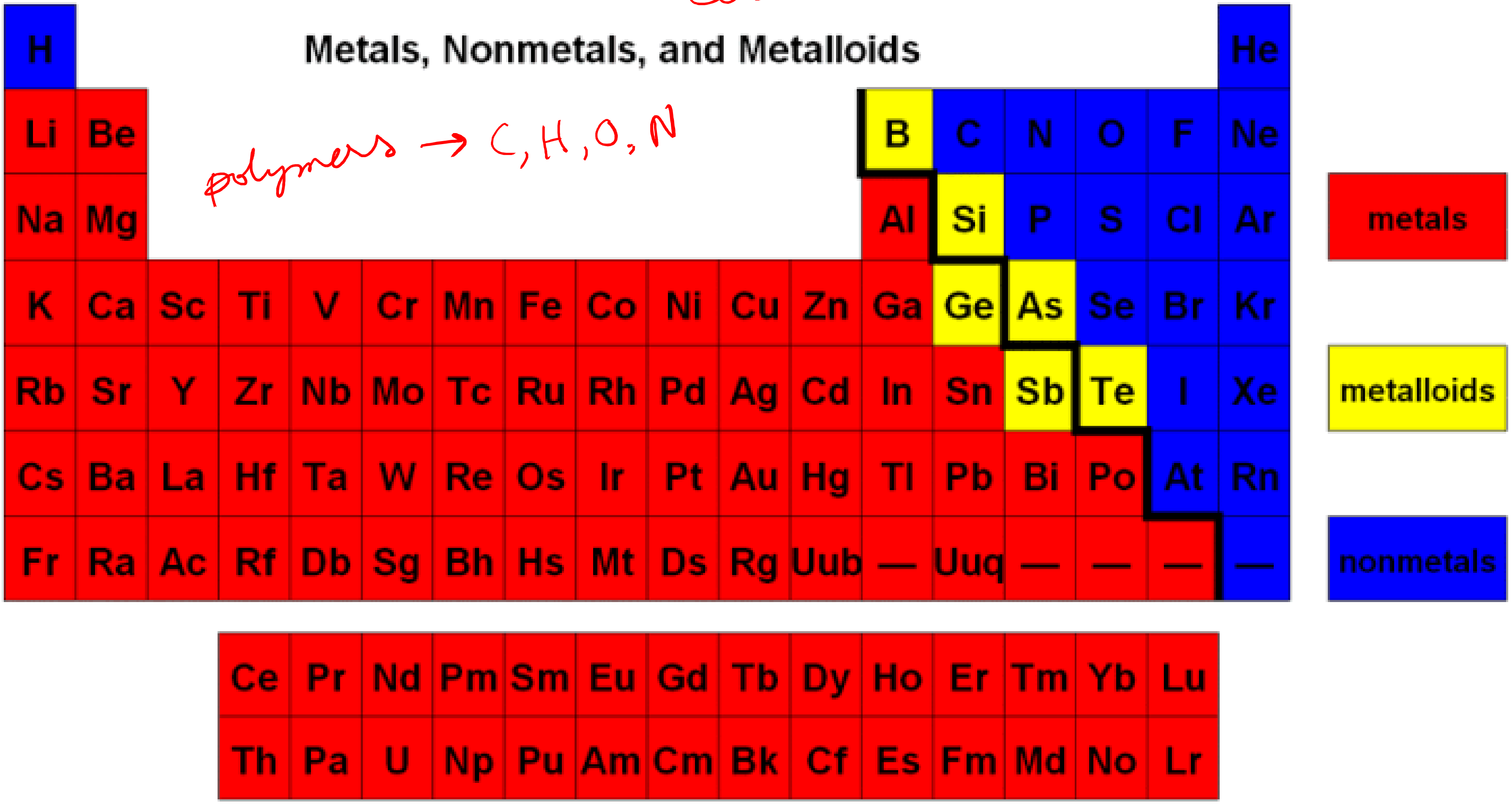


Classification of Materials-1



Metals vs Non-Metals

ceramics → oxides, carbides, nitrides



polymers → C, H, O, N

Classification of Materials-1

	Bonding	Microstructure	Advantages	Disadvantages
METALS and ALLOYS	metallic	crystal grains	• strong, stiff • ductile • conductive	• fracture • fatigue • corrosion
POLYMERS	covalent and secondary	chain molecules	• low cost • light weight • resist corrosion	• low strength • low stiffness • creep (high temp.)
CERAMICS and GLASSES	ionic-covalent	crystal grains amorphous	• strong, stiff, hard • resist temperature • resist corrosion	• brittleness
COMPOSITES	various	matrix and fiber, etc.	• strong, stiff • lightweight	• high cost • delamination

[Mechanical Behaviour of Materials, Norman E. Dowling]

Types of engineering materials

Metals/metallic materials
- good conductors of electricity and heat
- lustrous appearance
- susceptible to corrosion
- strong, but deformable

Ceramics & Glasses
- thermally and electrically insulating
- resistant to high temperatures and harsh environments
- hard, but brittle

Polymers
- very large molecules
- low density, low weight
- maybe extremely flexible

Composites
- consist of more than one material type
- designed to display a combination of properties of each component

Ceramics: Al_2O_3, SiC, SiO_2 (oxides, nitrides and carbides)- bricks, refractories

Polymers: Plastic and rubber materials, organic – C, H_2, other non-metallic materials

Composites: Concrete, plywood, fiberglass

Metals and alloys

Metals & Alloys

Ferrous

- Steels
- Cast Irons

Plain Carbon Steels
Alloy Steels

White Cast Iron
Malleable Cast Iron
Grey Cast Iron

Non-ferrous

- Cu-Alloys
- Ni-Alloys
- Al-Alloys
- Ti-alloy
- Superalloy → Ni, Cr

Metals and alloys

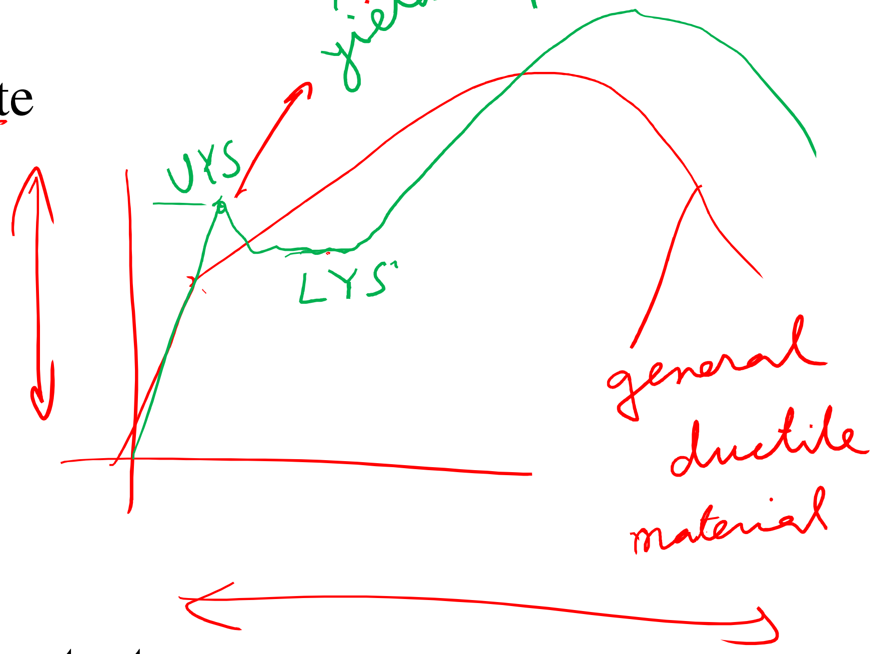
some special materials (e.g. low C steel)
↑
yield POINT phenomenon

Plain Carbon Steels: Iron + carbon
Small amount of P, S, Mn, Si

Low carbon steel < 0.3% C 0.25% C
Structure are usually ferrite and pearlite

Medium carbon steel 0.3 – 0.6% C
Form bainite or Martensite

High carbon steel > 0.6% C
Can form Martensite



✓ Strength increases with increasing carbon content

✓ Ductility, toughness – decreases with increasing carbon content

strength ductility

Metals and alloys

Alloy steel:

- Alloying elements are added to steels in small quantity (usually less than 5%) t
improve strength or hardenability

- Alloying elements is added to much quantity (upto 20%) to produce special propertie
(such as corrosion resistance)

(11% Cr → stainless steel
↳ resist corrosion)

Alloying elements: Mn, Si, Cu, Cr, Ni, Mo, V, W, Co, B, P, S

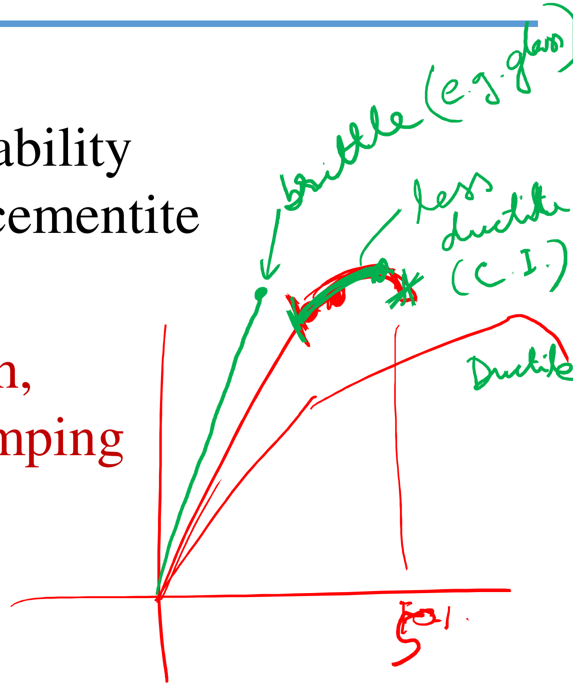
HSLA steel – structural application (bridges and building)
Microalloyed steel – substitutes for heat treated steel
Maraging steel – super high strength and toughness
Stainless steel – corrosion resistance
Tool steel – wear resistance, toughness and high strength
Silicon steel – electric and magnetic application

Metals and alloys

Cast iron: Alloys more than 2% carbon

(C.I.)

- Mo and Ni are frequently added to improve hardenability
- Properties decided by the formation of graphite of cementite



Gray cast iron – low ductility, excellent compressive strength, machinability, wear resistance, sound and damping characteristics

- carbon in the form of graphite flakes

White cast iron – carbon in the form of carbide

- very hard and brittle
- applied where abrasion resistance is required

Malleable cast iron – controlled heat treatment of white cast iron

- Cementite dissociates and forms regular graphite spheroids
- greater ductility than gray cast iron

-

Brittle
↳ relative term

Metals and alloys - Summary

- **Ferrous:** iron as main constitute
- **Non ferrous:** other than iron as main constitute
- **Steel:** carbon less than 2 %
- **Cast iron:** carbon more than 2%
- **Cu alloy:** Pure Cu – electrical industry
- **Al alloy:** Automotive frame
- **Ni alloy:** Outstanding strength and corrosion resistance
- **Ti alloy:** High temperature engineering material
- **Superalloys:** High strength, creep resistance, oxidation and corrosion resistance, fatigue resistance even at high temperature
  - Jet engine, rocket and nuclear application
  - Ni based – Inconel, Hastelloy
  - Iron-based
  - Cobalt- based

Polymer

Thermosetting:

- At elevated temperature it is soften with increasing temperature.
- When it cooled, becomes harder and stronger.
- No chemical change is involved.
- Thermosetting polymer is significantly stronger and more rigid than thermoplastic

Thermoplastic:

- Soften over a range of temperature.
- It is formed by $\boxed{\text{injection molding}}$ → VI
- Large amount of permanent deformation is available.
- Having useful strength.

Thermoplastic - heat forming
Thermoset - heat setting

Thermoplastic - bonds are covalent
Thermoset - bonds are covalent and crosslinked

Elastomers

Elastomer: Elastic polymer, special class of linear polymer that display large amount of elastic deformation

Acquire crosslinked structure

Natural rubber – oldest elastomer
Polyurethanes - Used in the textile industry for the manufacture of elastic clothing
Polybutadiene - used on tires of vehicles
Neoprene – wetsuits, wire insulation, industrial belts
Silicone - Medical prostheses

Composites

Comprised of two or more physically distinct materials with at least one material providing reinforcing properties

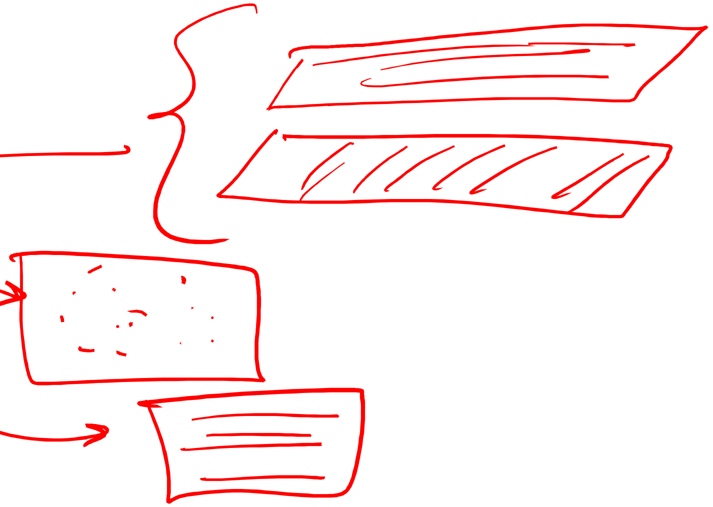
Natural Composites: Bone, Wood, Bamboo

Engineering Composites: Glass fibers, carbon fibers, synthetic fibers, metal fibers, ceramic fibers

particles

Composites

- Laminar
- Particle Reinforced
- Fibre Reinforced



Ceramics and Glasses

- ✓ Complex compounds and solutions that contain both metallic and nonmetallic elements (C, N, O, P, or S)
- ✓ typically hard and brittle
- ✓ exhibit high strength and high melting points
- ✓ exhibit low thermal and electrical conductivity
- ✓ Good chemical and thermal stability, good creep resistance
- ✓ Can be made amorphous structure with a random pattern, like glass (silicates)

Applications: Pottery, brick, tile, glass, ovenware, magnets, refractories, cutting tools

Types: Aluminum oxide, Magnesium oxide, silicon oxide, silicon nitride

Semiconductors

- Conduct electricity intermediately (Neither good conductor nor good insulator)
- Si, Ge, Sn in periodic table serve as a boundary between metallic and nonmetallic elements
- Si and Ge are widely used semiconductors
- O to Te(Tellurium) and Zn to Hg (Mercury) are used with Si and Ge to form a semi conductor
- GaAs (Gallium Arsenide) which is used as a high temperature rectifier and a laser material
- CdS which is used as a low-cost solar cell for conversion of solar energy to electrical energy
- Some ceramics display semi-conducting behavior, e.g., ZnO which is widely used in color television

Physical properties

Thermal conductivity: Property of a material to conduct heat flow

High thermal conductivity material – Copper, Aluminum, Silver, Gold

Materials with low thermal conductance – Polymer, alumina – can be used for insulation purpose

Thermal expansion - Change in volume in response to change in temperature

- ✓Creates thermal strain in solid
- ✓Degree of expansion per unit change in temperature is called the material's **coefficient of thermal expansion**
- ✓However, it varies with temperature

Mechanical properties

Strain(ε): Change in dimension per unit original dimension

Stress (σ or τ): Applied force per unit area

Normal Stress and Shear stress

Strength: Ability of a material to resist the applied force without breaking or yielding.

Stiffness: Ability of material to resist deformation under stress

Elasticity: Property of material to regain its original shape after deformation when the external force are removed

Steel is more elastic than rubber

Plasticity: Property of a material which retains permanent deformation with the applied load

Mechanical properties

tension
compression

Ductility: Ability of a material enabling it to be drawn in to wire with the application of a tensile force

Brittleness: It is property of a material opposite to ductility.

Cast iron is a brittle material

Malleability: Special case of ductility which permits materials to be rolled or hammered in to thin sheets.

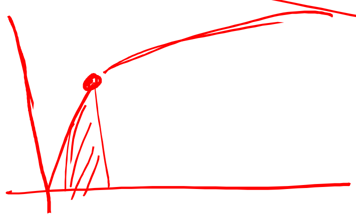
compression

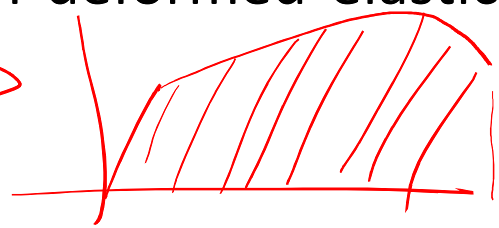
Ex. aluminum

Toughness: Property of material to resist fracture due to high impact load

Measurement - Energy absorbed before fracture

Resilience: Amount of energy when deformed elastically and release upon unloading





Mechanical properties

Creep: Material is subjected to a constant stress at elevated temperature for long period of time - it creates slow and permanent deformation

Creep → kind of plastic deformation at high temperature

Fatigue: When a material is subjected to cyclic stresses, it fails below yield point stress

Hardness: Resistance to wear or scratching

Other properties

- ✓ Latent Heat of Material, Thermal diffusivity
- ✓ Viscosity
- ✓ Electrical conductivity, Electrical resistivity
- ✓ Magnetic properties – induction welding

- ✓ In machining, welding, casting - thermal properties of the work is important
- ✓ Casting and welding – Fluid property is significant
- ✓ Semiconductor manufacturing - electrical properties of silicon is important
- ✓ Mass diffusion coefficient – surface hardening or diffusion welding

Properties evaluation

Characteristics of sample by different experimental techniques

Physical properties: Density, melting point, optical properties, thermal properties of specific heat, coefficient of thermal expansion and thermal conductivity, electrical conductivity, and magnetic properties

Microstructural characterization: Optical microscope, Scanning electron microscopy, X-ray diffraction , Transmission electron microscopy (SEM) (XRD) (TEM)

Mechanical properties: Static properties

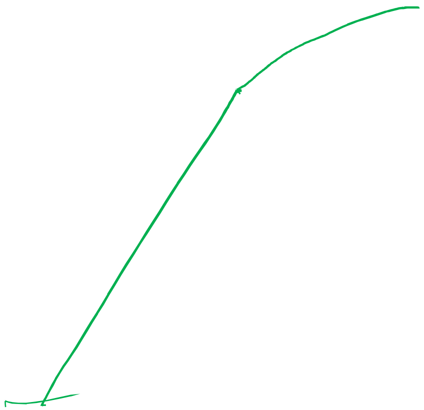
Uniaxial tensile testing – standard specimen

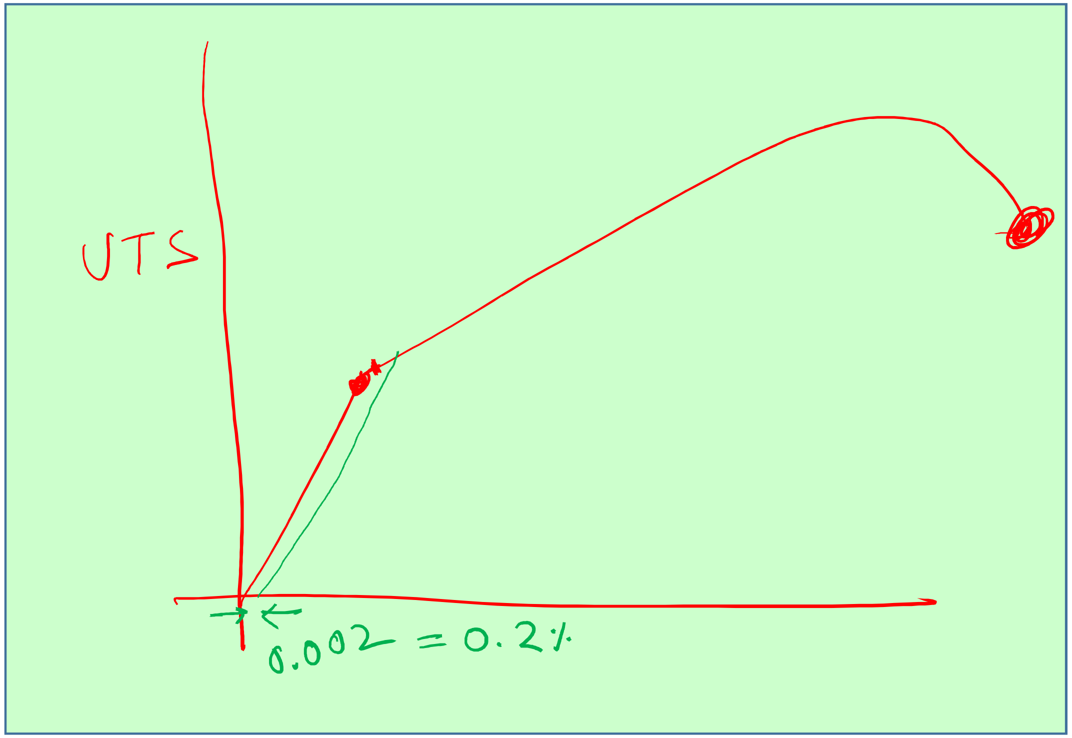
Size effect is eliminated – engineering stress-strain curve as compared to load-deflection curve

Mechanical Properties

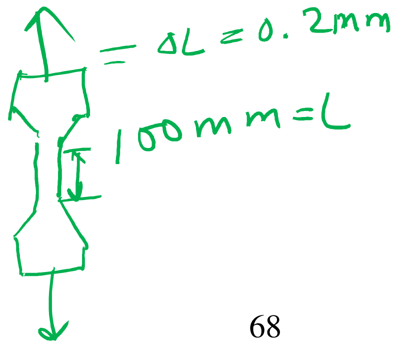
Characteristic information from stress-strain curve

Proportional limit, Young's modulus, Resilience or Modulus of Resilience, Yield strength, Offset yield point (0.2% strain), Ultimate tensile strength, Fracture strength





Toughness ✓

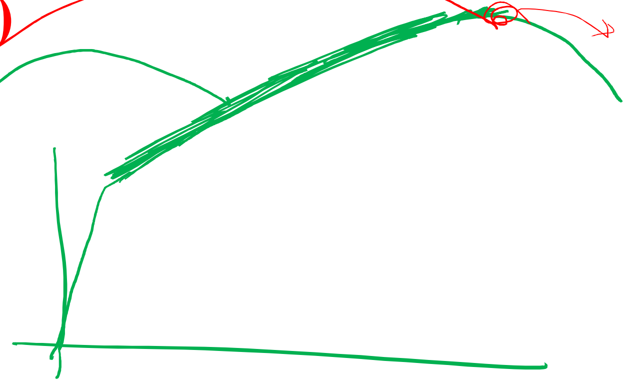


Mechanical Properties

Ductility and Brittleness

Toughness

True stress-strain curve (Mostly increasing order)



Elongation – uniform and non-uniform, necking

Strain-hardening

Damping capacity – Loading and unloading path are different

Gray cast iron – high damping capacity

Steel – transmits sound and vibration

Dynamic Properties

Loading condition in engineering components

- ✓ Impact load or rapidly change in magnitude
- ✓ Repeated cycle of loading and unloading
- ✓ Frequent change in mode of loading

Impact test – to evaluate the fracture resistance of material

Charpy test – simply supported bean with notch

Izod test – cantilever beam with notch

Fatigue testing: Cyclic loading pattern is followed or entirely random variation in stress is followed

Count number of cycles to induce failure

Stress vs. number of cycles curve

May conducted at different temperature

Creep Properties

Properties at elevated temperature subjected to constant load

Tensile specimen elongate continuously until rupture occurs even the applied stress is below yield strength at that temperature

Important for: Gas turbine, power plant, high-temperature pressure vessel

Represented by strain vs. time curve at a particular temperature

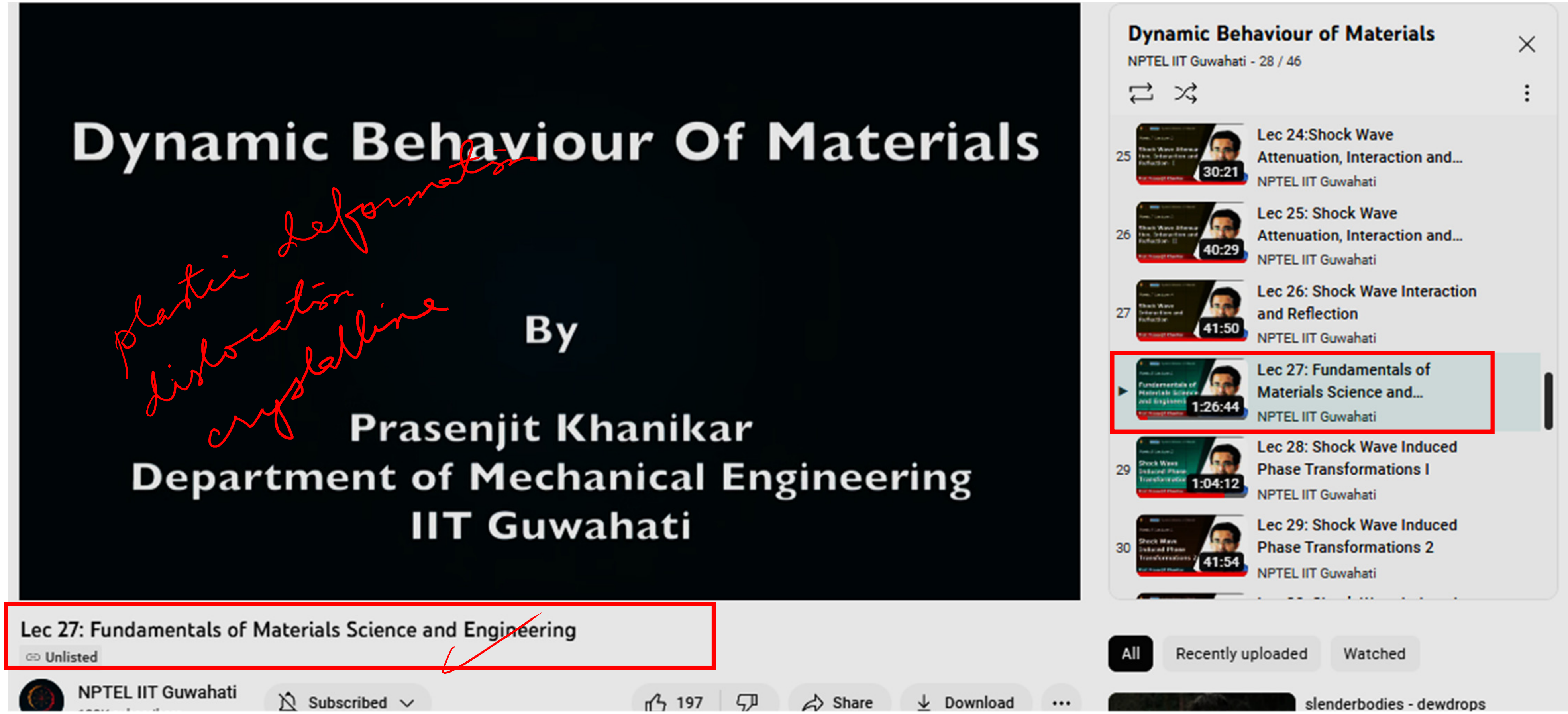
Properties evaluation

Physical properties: Standard experimental methodologies

Microstructural measurement:
Average grain size and distribution – line intercept method
Residual stress - X-ray diffraction (XRD) method, Neutron diffraction
Chemical composition of a metallic sample – Energy Dispersive X-Ray Analysis (EDX)
Various phases in component – XRD method

X

Review of fundamentals of Materials Science and Engineering



https://www.youtube.com/watch?v=ZN4B_TgCylI&list=PLwdnzlV3ogoX8Guw6jEVdspn21ueKV0ib&index=28

End of Module 1

Introduction to Manufacturing processes