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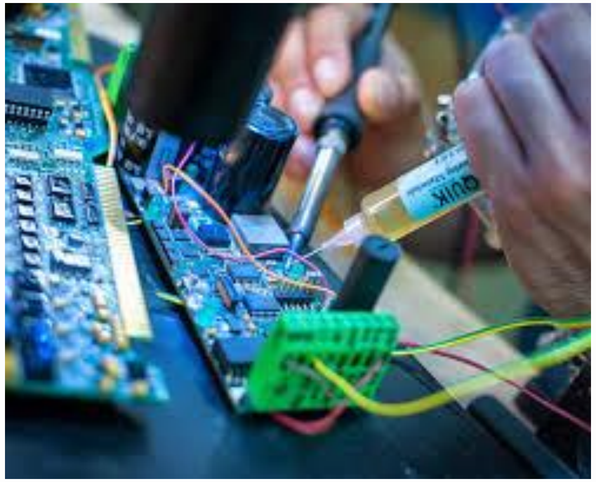
Department of Mechanical Engineering
RV College of Engineering®, Bengaluru – 560059

ELEMENTS OF MECHANICAL ENGINEERING

UNIT-I (6 hours): Engineering Materials

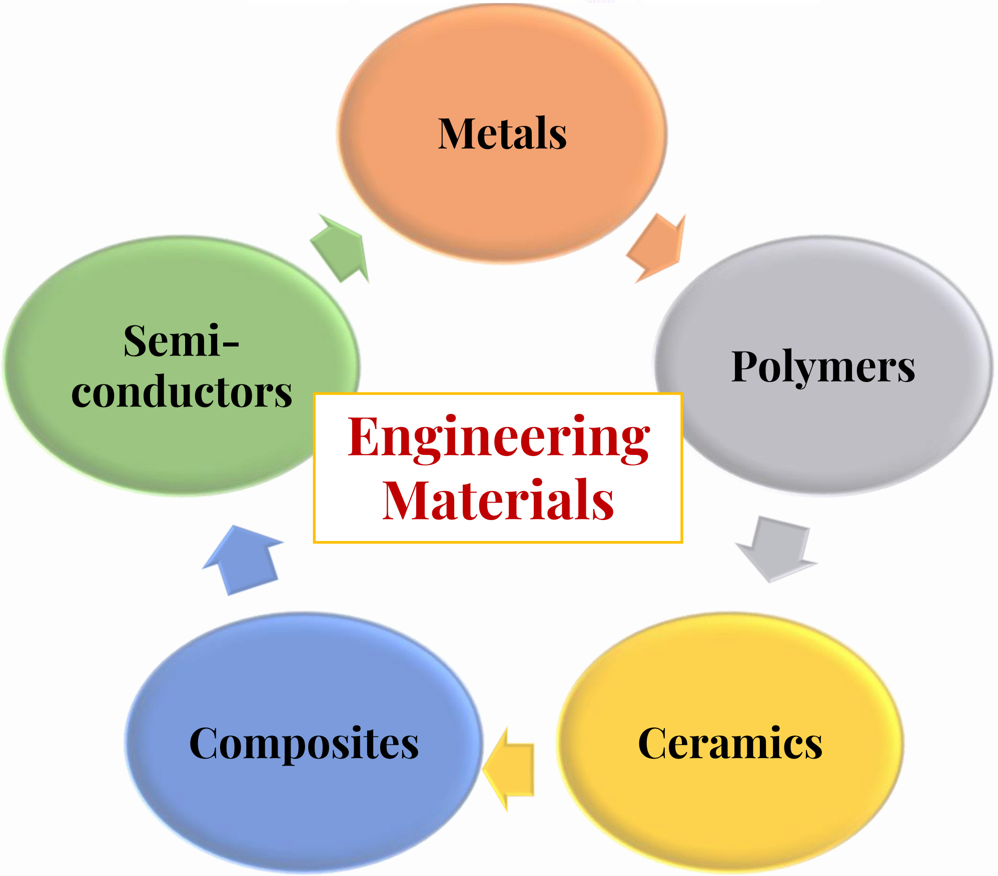
Engineering materials: introduction and classification: metals (Ferrous and Non ferrous), Polymers (thermoplastics, Thermosets and Elastomers), Ceramics and Composites

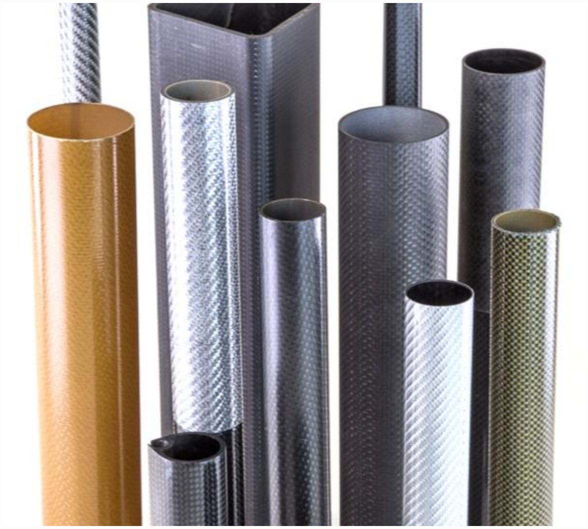
Material Properties and Applications: Physical, mechanical, optical, electrical and electronics, thermal and chemical properties. Applications: Aerospace, Automotive, Electronic and Biomedical




Brass
Cast Iron
Bronze
Steel
Copper


Polyethylene
Polyvinyl chloride
Polypropylene
Polytetrafluoroethylene (Teflon)
Polydichloroethylene (Saran)
Polystyrene
8

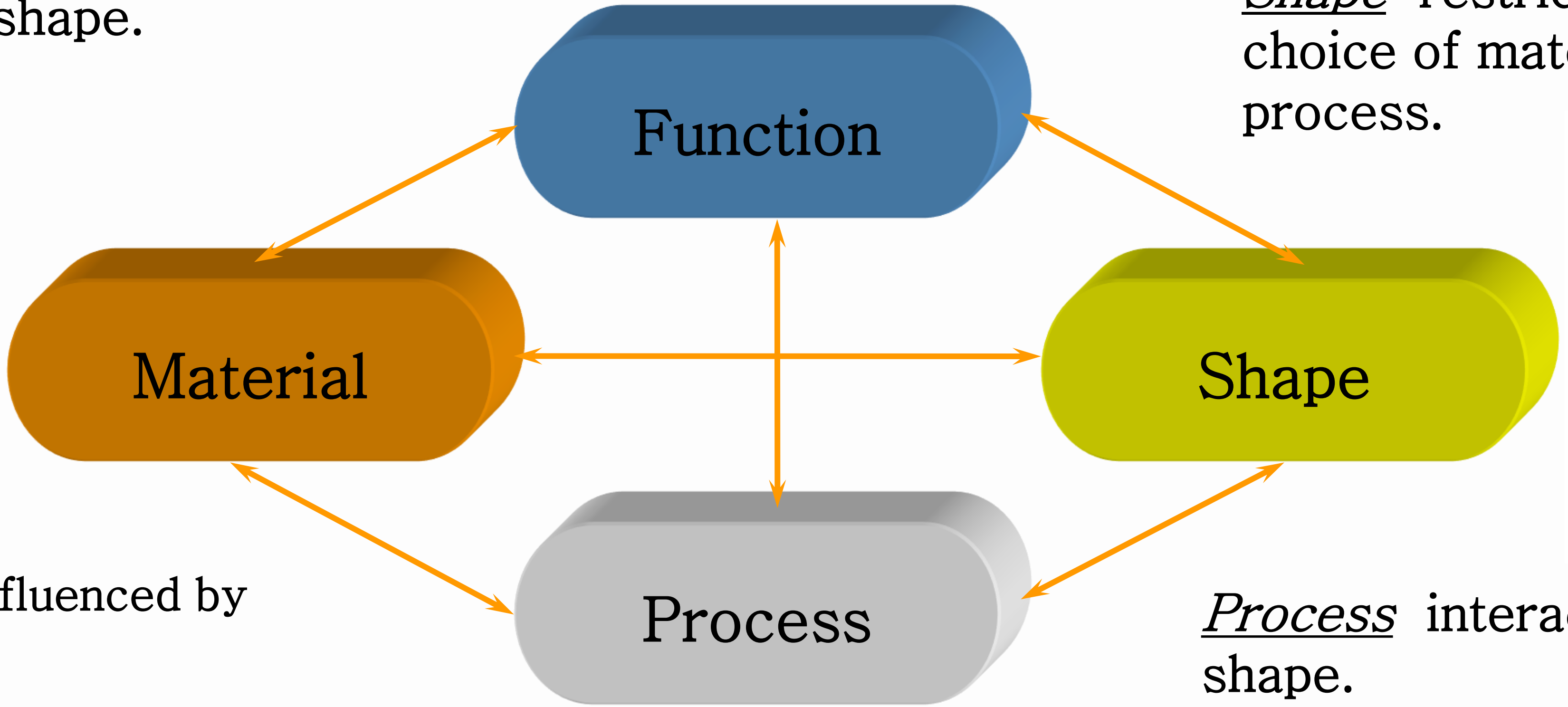

Metals
Polymers
Ceramics
Composites
Semi-conductors
Engineering Materials



Introduction: material selection

Function dictates the choice of material and shape.

Shape restricts the choice of material and process.



Process is influenced by *material*

Process interacts with shape.

Material selection and process cannot be separated from the shape and the function of the product, two way interaction.

Periodic Table

Periodic table of the elements

- Alkali metals
- Alkaline-earth metals
- Transition metals
- Other metals
- Other nonmetals
- Halogens
- Noble gases
- Rare-earth elements (21, 39, 57–71) and lanthanoid elements (57–71 only)
- Actinoid elements

period \ group	1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

lanthanoid series 6	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
actinoid series 7	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

*Numbering system adopted by the International Union of Pure and Applied Chemistry (IUPAC).

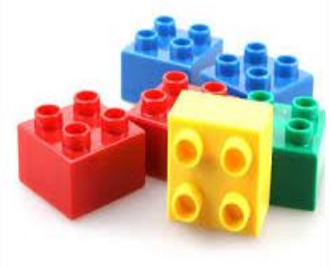
Classification of Engineering Materials

Materials

- **Metals**
  - **Ferrous**
    - Steel
    - Stainless steel
    - Die & tool steel
    - Cast iron
  - **Non-ferrous**
    - Aluminum
    - Copper
    - Titanium
    - Tungsten
- **Polymers**
  - **Thermoplastics**
    - Nylon
    - ABS
    - Polyethylene
    - Polycarbonate
    - PVC
  - **Thermosets**
    - Phenolic
    - Polyamide
    - Epoxies
    - Polyester
  - **Elastomers**
    - Rubber
    - Polyurethane
    - Silicone
- **Ceramics**
  - Carbides
  - Nitrides
  - Graphite
  - Diamond
  - Glasses
- **Composites**
  - Reinforced plastics - Laminates
  - Metal-Matrix
  - Ceramic-Matrix

Classification of Engineering Materials

Polymers



Thermoplastics

- Nylon
- ABS
- Polyethylene
- Polycarbonate
- PVC

Thermosets

- Phenolic
- Polyamide
- Epoxies
- Polyester

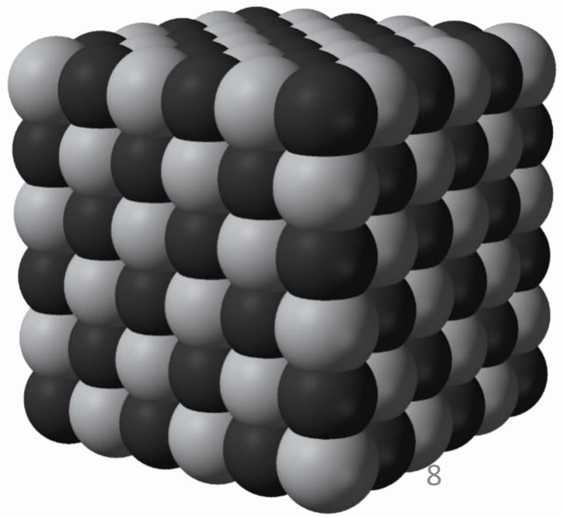
Elastomers

- Rubber
- Polyurethane
- Silicone

Metals

- **A solid material which is typically hard, shiny, malleable, fusible, and ductile, with good electrical and thermal conductivity (e.g. iron, gold, silver, and aluminum, and alloys such as steel).**

The atoms of metallic substances are closely positioned to neighboring atoms in one of two common arrangements.



Classification of Metals

Metals

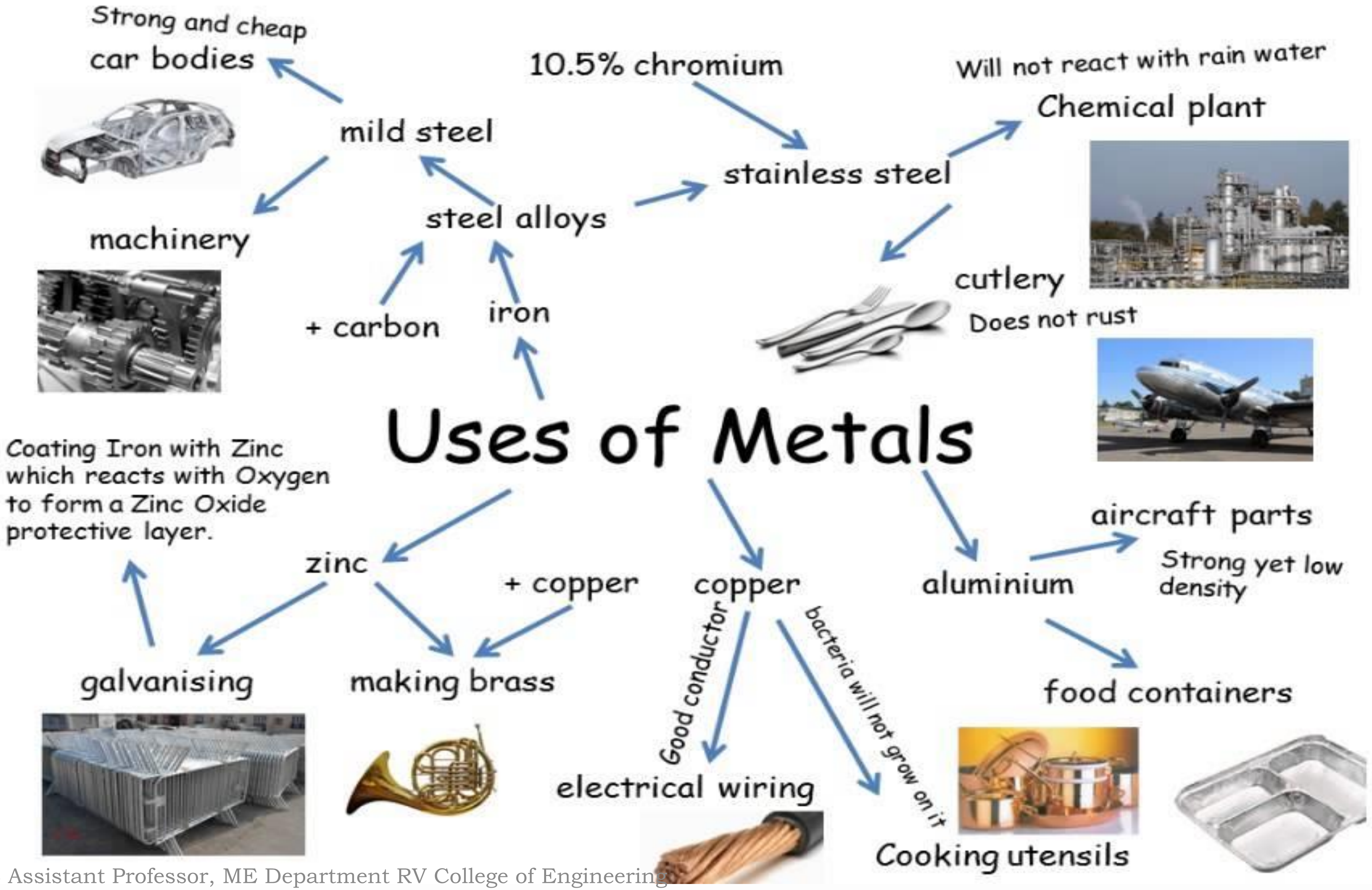
- ***Ferrous*** — *Has iron as main constituent*
  - Steel
  - Stainless steel
  - Die & tool steel
  - Cast iron
- ***Non-ferrous*** — *Does not have iron as Main constituent*
  - Aluminum
  - Copper
  - Titanium
  - Tungsten

Properties of Metals

- Strong
- Malleable and ductile
- React with oxygen to form basic oxides
- Sonorous
- High melting and boiling points
- Good conductors of electricity
- Good conductors of heat
- Mainly solids at room temp. Exception mercury - liquid at room temp.
- Shiny when polished
- When they form ions, the ions are positive
- High density

Uses of Metals

- They are made into jewelry due to their hard and shiny appearance.
- They are used to make pans, since they are good conductors of heat.
- They are used in electrical cables, because they are malleable, ductile and good conductors of electricity.
- They are strong so used to build scaffolding and bridges.
- They make a ringing sound, sonorous, hence their use in bell making.


Uses of Metals
iron
steel alloys
+ carbon
mild steel
car bodies
Strong and cheap
machinery
10.5% chromium
stainless steel
Chemical plant
Will not react with rain water
cutlery
Does not rust
zinc
Coating Iron with Zinc which reacts with Oxygen to form a Zinc Oxide protective layer.
galvanising
+ copper
making brass
copper
Good conductor
electrical wiring
bacteria will not grow on it
Cooking utensils
aluminium
aircraft parts
Strong yet low density
food containers

Polymers

A compound of high molecular weight derived either by the addition of any smaller molecules, as polyethylene, or by the condensation of many smaller molecules with the elimination of water, alcohol, or the like, as nylon.

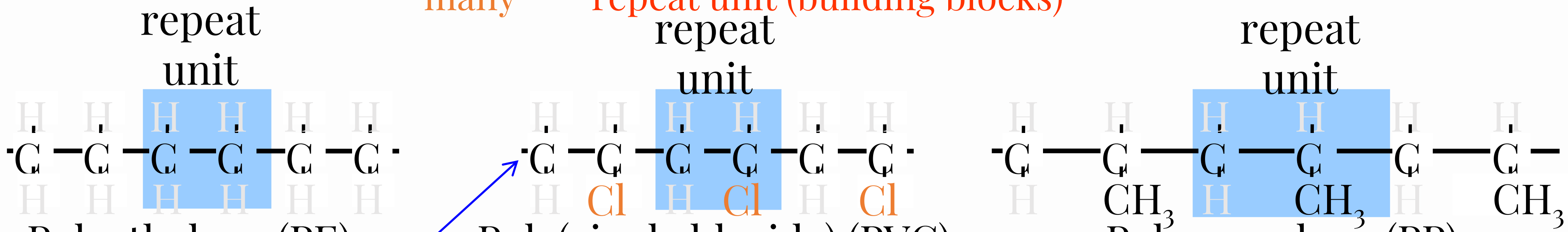
- **Natural polymers:** amber, wool, silk and natural rubber have been used for centuries.
- **Synthetic polymers:** includes synthetic rubber, phenol formaldehyde resin (or Bakelite) neoprene, nylon, polyvinyl chloride, polystyrene, polyethylene, silicone.

Polymers

- A compound consisting of long-chain molecules, each molecule made up of repeating units connected together
- There may be thousands, even millions of units in a single polymer molecule
- The word polymer is derived from the Greek words poly, meaning many, and **meros** (reduced to mer), meaning **part**
- Most polymers are based on carbon and are therefore considered organic chemicals

Poly mer

many repeat unit (building blocks)



Polyethylene (PE) Poly(vinyl chloride) (PVC) Polypropylene (PP)

Carbon chain backbone

Classification of Polymers

- **Polymers can be separated into plastics and rubbers**
- As engineering materials, it is appropriate to divide them into the following three categories:

1. Thermoplastic polymers
2. Thermosetting polymers
3. Elastomers

where (1) and (2) are plastics and (3) are rubbers

General Characteristics of Polymers

1. **Polymers have long chain structures.** The individual molecule of a polymer is very large, i.e., it may consists of thousands of similar small molecules, all bonded together covalently
2. **All polymers have one thing common, i.e., carbon**, which further bonds with hydrogen, nitrogen, halogens or other organic or inorganic substances
3. **Although, polymer's structure may be crystalline in simple materials but generally they are non-crystalline solids at room temperatures.** No doubt, polymers pass through a viscous stage during formation
4. **Polymers have light weight** and they can be easily fabricated and shaped.
5. **They are poor conductors of electricity** and their thermal conductivity is also low.
6. Moreover, **the polymers are resistant to chemical attack and decay**

Properties of Polymers

Polymers

- Can be very resistant to chemicals.
- Can be both thermal and electrical insulators.
- Generally, polymers are very light in weight with significant degrees of strength.
- Can be processed in various ways.
- Are materials with a seemingly limitless range of characteristics and colors.
- Are usually made of petroleum, but not always.
- Can be used to make items that have no alternatives from other materials.

Difference between Thermoset and Thermoplastic Polymers

SI No.	Thermosetting Plastics	Thermoplastics
1	Three dimensional network of primary covalent bonds with cross linking between chains	Linear polymers without cross linking and branching
2	Upon heating they retain their strength and prolonged heating causes roasting of polymers and ultimately depolymerisation	Upon heating the secondary bonds between individual chains break, the polymers become soft and on cooling hard and rigid because secondary bonds re-establish themselves
3	Harder, stronger and more brittle	strong and less brittle
5	It is difficult to fill an intricate mold with such plastics	They can fill the complicated mold quite easily
6	can not be recycled	can be recycled
7	Ex: polyesters, silicones, Bakelite etc.	PVC, Nylons, polyethylene
8	Applications: manufacture of telephones, electrical outlets, appliance handles etc.	Applications: Plastic walls, floor tiles, reflectors, plastic lenses etc.

Elastomers

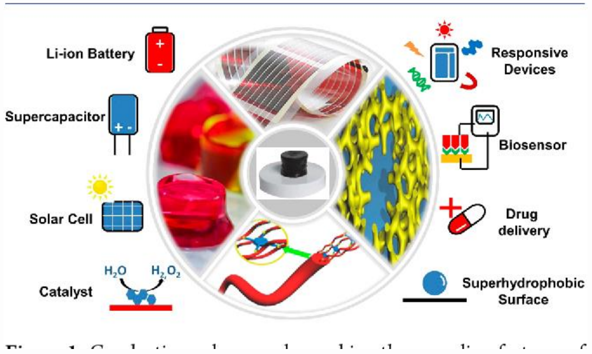
- Polymers capable of large elastic deformation when subjected to relatively low stresses
- Some can be extended 500% or more and still return to their original shape
- **Two categories:**
  1. Natural rubber - derived from biological plants
  2. Synthetic polymers - produced by polymerization
- processes similar to those used for thermoplastic and thermosetting polymers

Characteristics of Elastomers

- **Elastomers consist of long-chain molecules that are cross-linked (like thermosetting polymers)**
- They owe their impressive elastic properties to two features:
  1. Molecules are tightly linked when unstretched
  2. Degree of cross-linking is substantially less than Thermosets

Applications of Polymers

- While plastics are used as a common example of polymers, there are many other materials which are also polymers.
- Proteins, such as hair, nails, tortoise shell
- Cellulose in paper and trees
- DNA
- Rubber



Polymers

Domestic household

Packaging

Automobiles

Building construction

Electronics

Applications of Polymers

Applications of Polymers

Ceramics

- **Ceramic materials are inorganic, non-metallic materials made from compounds of a metal and a non metal. They are formed by the action of heat and subsequent cooling.**
  - Are of 2 types : Crystalline & Non-crystalline-glass

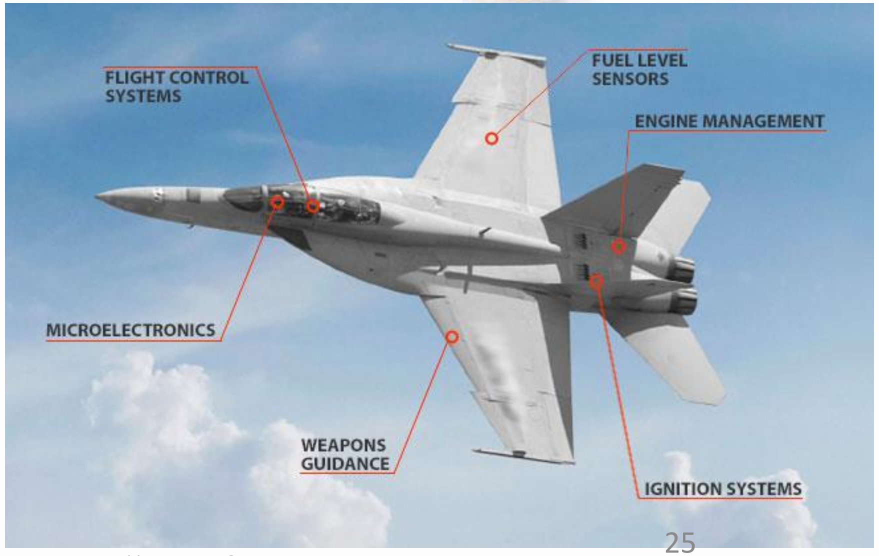
- Some ceramics are semiconductors. Most of these are transition metal oxides that are II-VI semiconductors, such as zinc oxide.
- Under some conditions, such as extremely low temperature, some ceramics exhibit high temperature superconductivity.

Properties of Ceramics

- Hard, Brittle
- Wear-resistant
- Refractory
- Thermal and Electrical Insulators
- Nonmagnetic
- Oxidation Resistant
- Prone To Thermal Shock And
- Chemically Stable

Applications of Ceramics

- **Aerospace:** space shuttle tiles, thermal barriers, high temperature glass windows, fuel cells
- **Consumer Uses:** glassware, windows, pottery, Corning¨ ware, magnets, dinnerware, ceramic tiles, lenses, home electronics, microwave transducers
- **Automotive:** catalytic converters, ceramic filters, airbag sensors, ceramic rotors, valves, spark plugs,
- **Medical (Bio ceramics):** orthopedic joint replacement, prosthesis, dental restoration, bone implants
- **Military:** structural components for ground, air and naval vehicles, missiles, sensors
- **Computers:** insulators, resistors, superconductors, capacitors, ferroelectric components, microelectronic packaging
- **Other Industries:** bricks, cement, membranes and filters, lab equipment
- **Communications:** fiber optic/laser communications, TV and radio components, microphones



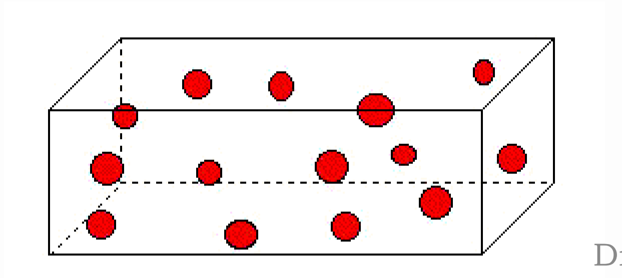
Composites

- **Composite materials** are **materials** made from two or more constituent **materials** with significantly different physical or chemical properties, that when combined, produce a **material** with characteristics different from the individual components

Typical engineered composite materials include:
- Composite building materials such as cements, concrete
- Reinforced plastics such as fiber-reinforced polymer
- Metal Composites

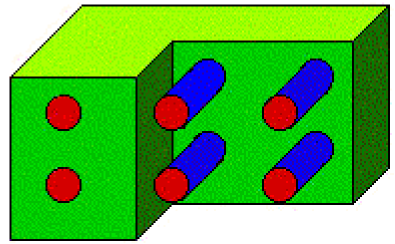
Particulate composite

materials contain a large number of randomly oriented particles. Ex: ceramic particles dispersed in a metallic matrix.



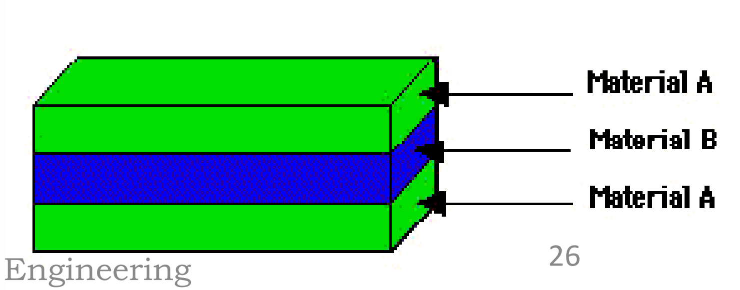
Fiber-reinforced composites

are composed of strong and stiff brittle fibers which are incorporated into a softer, more ductile matrix.



Laminar composites

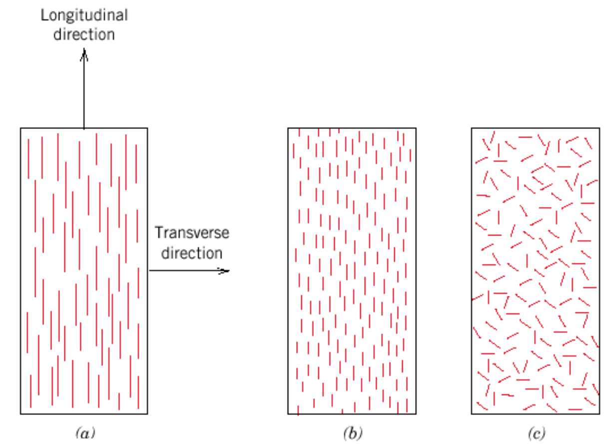
are Composed of layers of different materials, called laminates



Classification of Composites

Classification - Based on type of reinforcement

- Composites
  - Particle-reinforced
    - Large-particle
    - Dispersion-strengthened
  - Fiber-reinforced
    - Continuous (aligned)
    - Discontinuous (short)
      - Aligned
      - Randomly oriented
  - Structural
    - Laminates
    - Sandwich panels

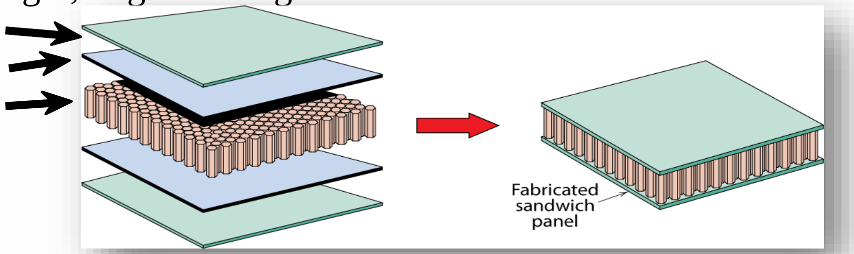


aligned continuous

aligned discontinuous

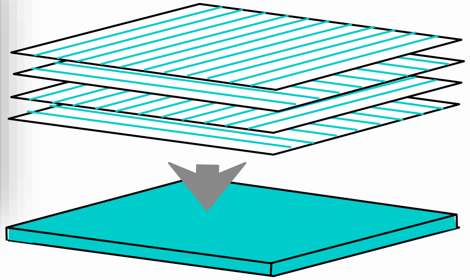
random

- Sandwich panels
  - -- low density, honeycomb core
  - -- benefit: light weight, large bending stiffness



Adapted from Fig. 16.18, *Callister 7e*. (Fig. 16.18 is from *Engineered Materials Handbook*, Vol. 1, *Composites*, ASM International, Materials Park, OH, 1987.)

- Laminate
  - Stacked and bonded fiber-reinforced sheets
    - -- stacking sequence: e.g., 0º/90º or 0°/45°/90º
    - -- benefit: balanced, in-plane stiffness



Adapted from Fig. 16.16, *Callister 7e*.

Properties of Composites

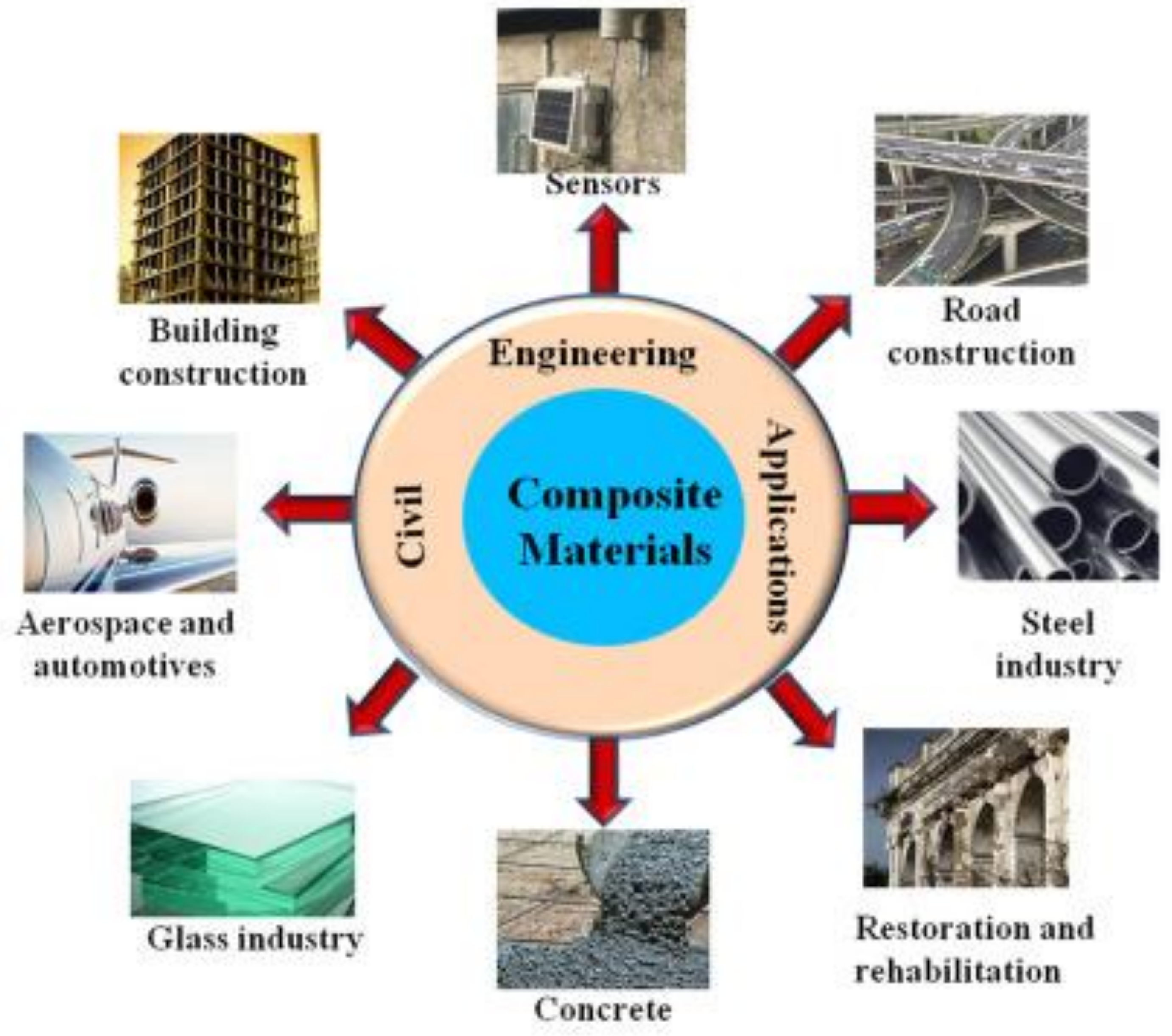
- **High Strength to Weight Ratio:** Fibre composites are extremely strong for their weight
- Fire Resistance
- **Chemical & Weathering Resistance:** Composite products have good weathering properties and resist the attack of a wide range of chemicals.
- **Translucency:** Polyester resins are widely used to manufacture translucent mouldings and sheets.
- **Manufacturing Economy:** due to their easy of production composite materials are economically easy to produce

Applications of Composites

- Light weight and strong - buildings, bridges and structures such as boat hulls,
- Carbon composite is a key material in today's launch vehicles and heat shields for the re-entry phase of spacecraft race car bodies,
- Used in storage tanks, imitation granite and cultured marble sinks and counter tops.
- Wood is a naturally occurring composite comprising cellulose fibers in a lignin and hemicellulose matrix.

- Applications:
  - Aerospace industry
  - Sporting Goods Industry
  - Automotive Industry
  - Home Appliance Industry

Applications of Composites



- ❖ Applications:
  - ❖ Aerospace industry
  - ❖ Sporting Goods Industry
  - ❖ Automotive Industry
  - ❖ Home Appliance Industry

Applications of Composites

(FRPs)

1.pipes, roofing's, storage containers, industrial floorings and automotive bodies

2.sports and recreational equipment's, pressure vessels and aircraft structural components.

3.military aircraft components, helicopter rotor blades and in some sporting goods.

4.Sic and Al_2O_3 fibre reinforced composites are used in tennis rackets, circuit boards and rocket cone noses.

(CMCs)

1. Concrete which contains steel rods in a matrix of cement , sand and crushed stones is extensively used in construction applications.

2.Sic particles reinforced in Titanium –di –boride matrix has good wear and corrosion resistance and hence can be used to produce heat exchangers.

(MMCs)

1.Boron fibre reinforced aluminium alloy matrix composites are used as structural members in space shuttles owing to its strength to weight ratio.

2.Al_2O_3 reinforced aluminium matrix finds applications in producing sporting equipment's and automobile engine parts.

Material properties

- **Physical Properties:** Solubility, Melting and Boiling point, Density, Color and luster, Odor, State, Texture, Viscosity
- **chemical properties:** Corrosion Resistance, Combustibility, Toxicity, Reactivity
- **Mechanical properties** –stress/strain curve for mild steel covering terminologies, hardness, brittleness, ductility, malleability.
- **Thermal properties-** Heat capacity, Coefficient of thermal expansion, thermal conductivity
- **Electrical and electronics properties –**resistivity, conductivity, dielectric strength, semiconductors
- **Optical properties-** Reflection, Refraction, Absorption

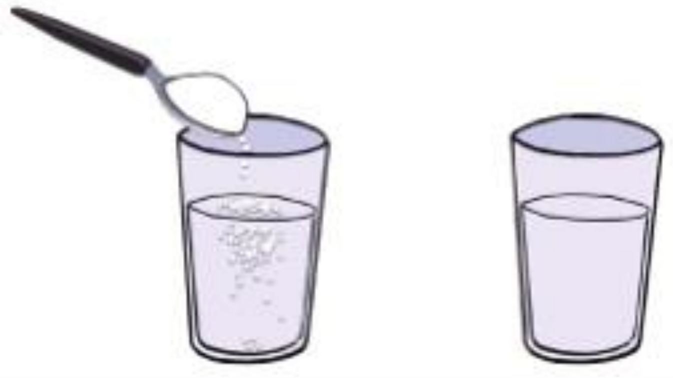
Physical Properties

Physical property is a property that can be easily observed without changing the identity of the substance.

- Can be **reversible**, or **irreversible**
- Substance may seem different, but the way the atoms link up is the same.

  - Solubility
  - Melting point
  - Boiling point
  - Density
  - Color and luster
  - Odor
  - State
  - Texture
  - Viscosity

Physical Properties



Solubility of a substance is its ability to dissolve.

Example: sugar in water

Melting and Freezing points are the temperatures at which a solid becomes a liquid and a liquid becomes a solid.

Density of a substance is a measure of how close together its particles are.
Low density = float
High density = sink

chemical properties

Chemical property is any ability to produce a change in the identity of matter. Chemical changes occur when a substance reacts and forms one or more new substances.

Examples of chemical properties . . .

1. Corrosion Resistance
2. Combustibility
3. Toxicity
4. Reactivity

reactivity
How readily a substance combines chemically with other substances.

flammability
Material' s ability to burn in the presence of oxygen.

Corrosive:
Eating away, such as a metal by acid

You know a chemical change has occurred when there is. . .

- ✓ A change in color or odor.
- ✓ Production of a gas (bubbling).
- ✓ Formation of a precipitate (solid).
- ✓ Absorb or release energy (gets hot or cold or light is given off).

Examples of Chemical Changes:

Burning Or Combustion:
Color change, odor change, Produces a gas, gets hot

Corroding:
Color change

Rusting:
Color change

Digesting:
Color change, odor Change, produces a Gas, releases energy

Molding:
Color change

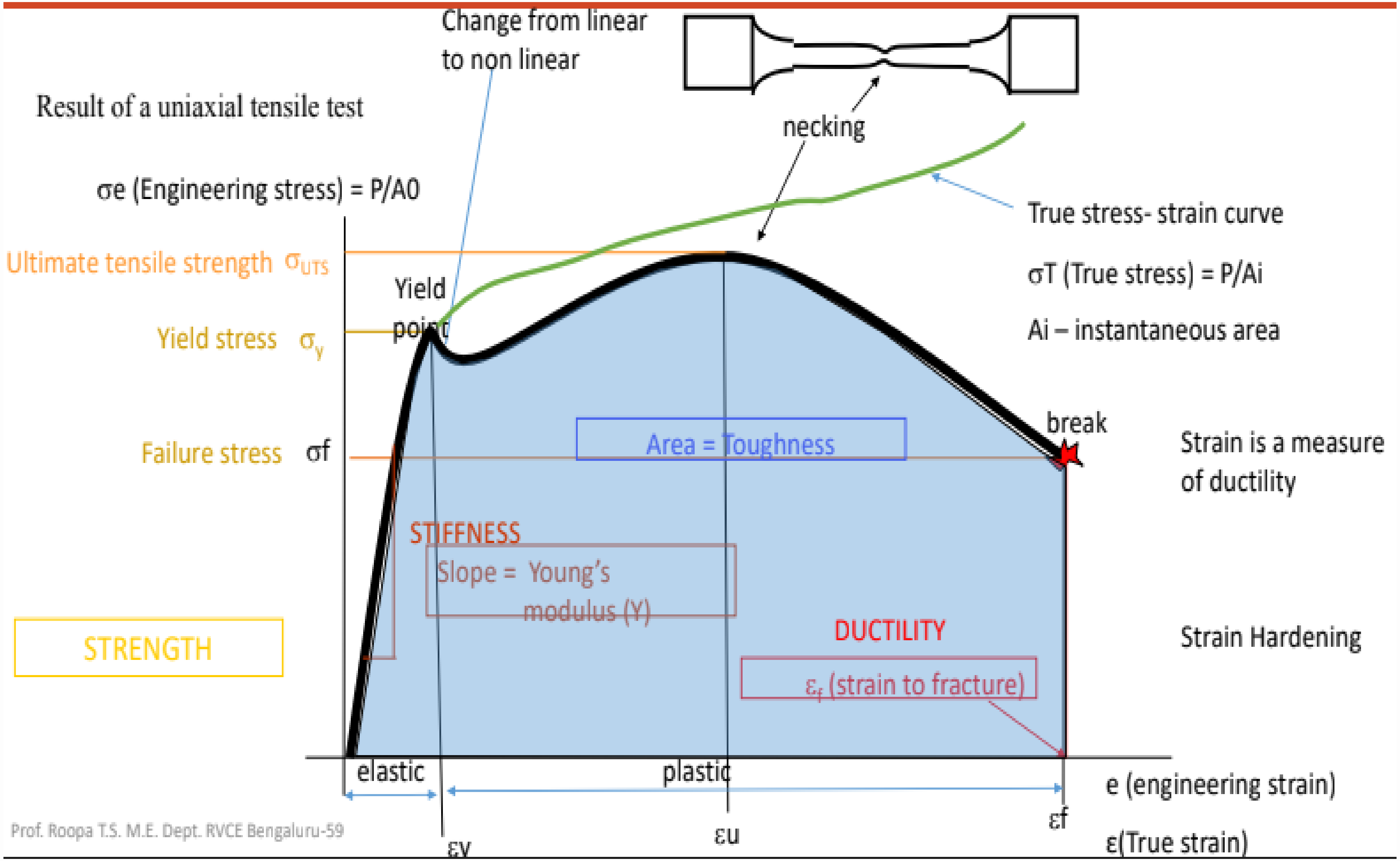
Decaying:
Color change

Mechanical properties

- The mechanical properties of a material are used to determine its suitability for a particular application. It is convenient to break the properties, and the tests that measure them, into several types:
- General properties of materials :
    - **Hardness:** resistance to penetration
    - **Brittleness:** failure at shock loads
    - **Ductility:** drawn out into wires
    - **Malleability:** beaten into sheets

- **Modulus of elasticity:** The initial slope of the curve, related directly to the strength of the atomic bonds.
- **Yield strength:** The point at which a consistent and measurable amount of permanent strain remains in the specimen.
- **Ductility:** The total elongation of the specimen due to plastic deformation, neglecting the elastic stretching
- **Toughness:** The total area under the curve which measures the energy absorbed by the specimen in the process of breaking.

The stress-strain diagram for a ductile material like mild steel



- The **specific heat** is the amount of **heat** per unit mass required to raise the temperature by one degree Celsius. The relationship between **heat** and temperature change is usually expressed in the form shown below where c is the **specific heat**.

$$C = \frac{Q}{m \times \Delta T}$$

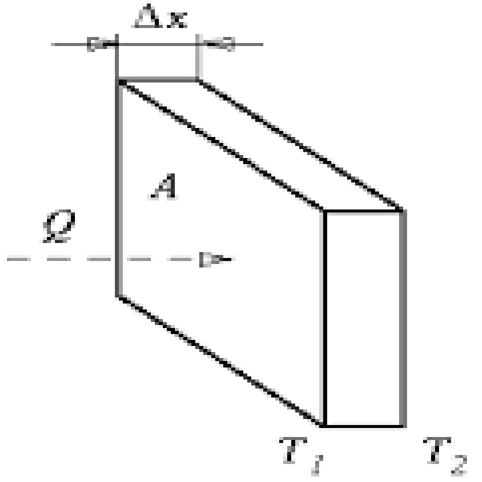
- **Coefficient of Thermal Expansion** (CTE) **Definition**: The **coefficient of thermal expansion** is **defined** as the fractional increase in the length per unit rise in temperature.

$$\alpha_V = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)$$

Thermal Conductivity

- The rate at which heat passes through a specified material, expressed as the amount of heat that flows per unit time through a unit area with a temperature gradient of one degree per unit distance.
- The opposite face is maintained at a temperature difference of 1 degree

$$k = \frac{Q\Delta x}{A(T_2 - T_1)}$$



Electrical and electronic conductivity

- **Ohms Law** : Ohm's law states that the current through a conductor between two points is directly proportional to the potential difference across the two points. Introducing the constant of proportionality, the resistance.

- **Resistivity** : a measure of the resisting power of a specified material to the flow of an electric current.

$$\rho = R\frac{A}{l}$$

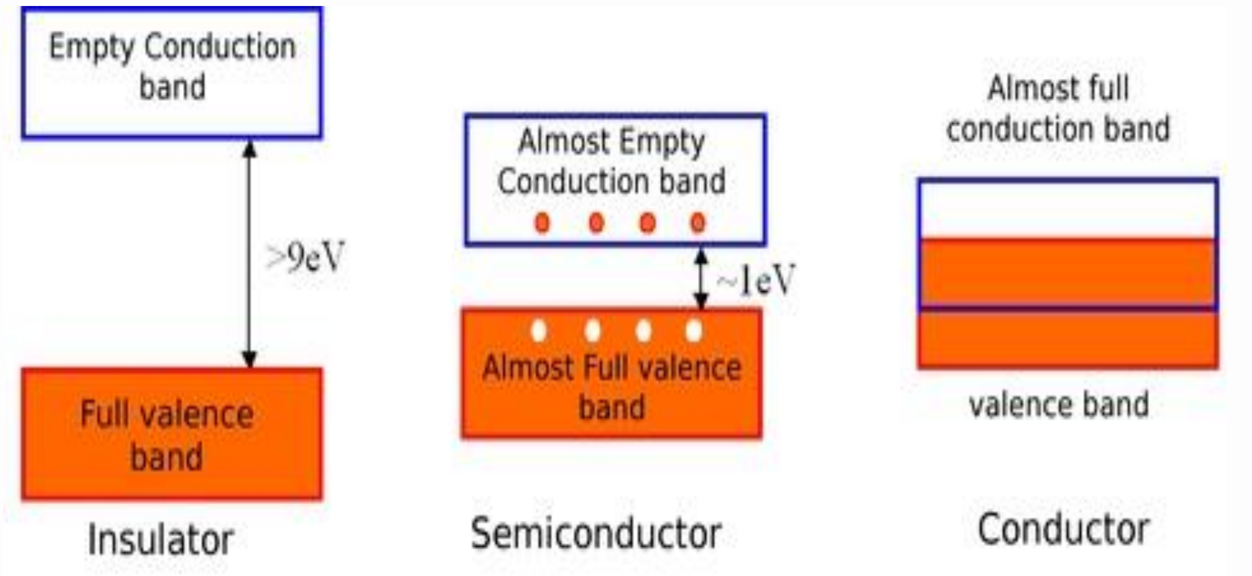
- **Conductivity**: The degree to which a specified material conducts electricity, calculated as the ratio of the current density in the material to the electric field which causes the flow of current.

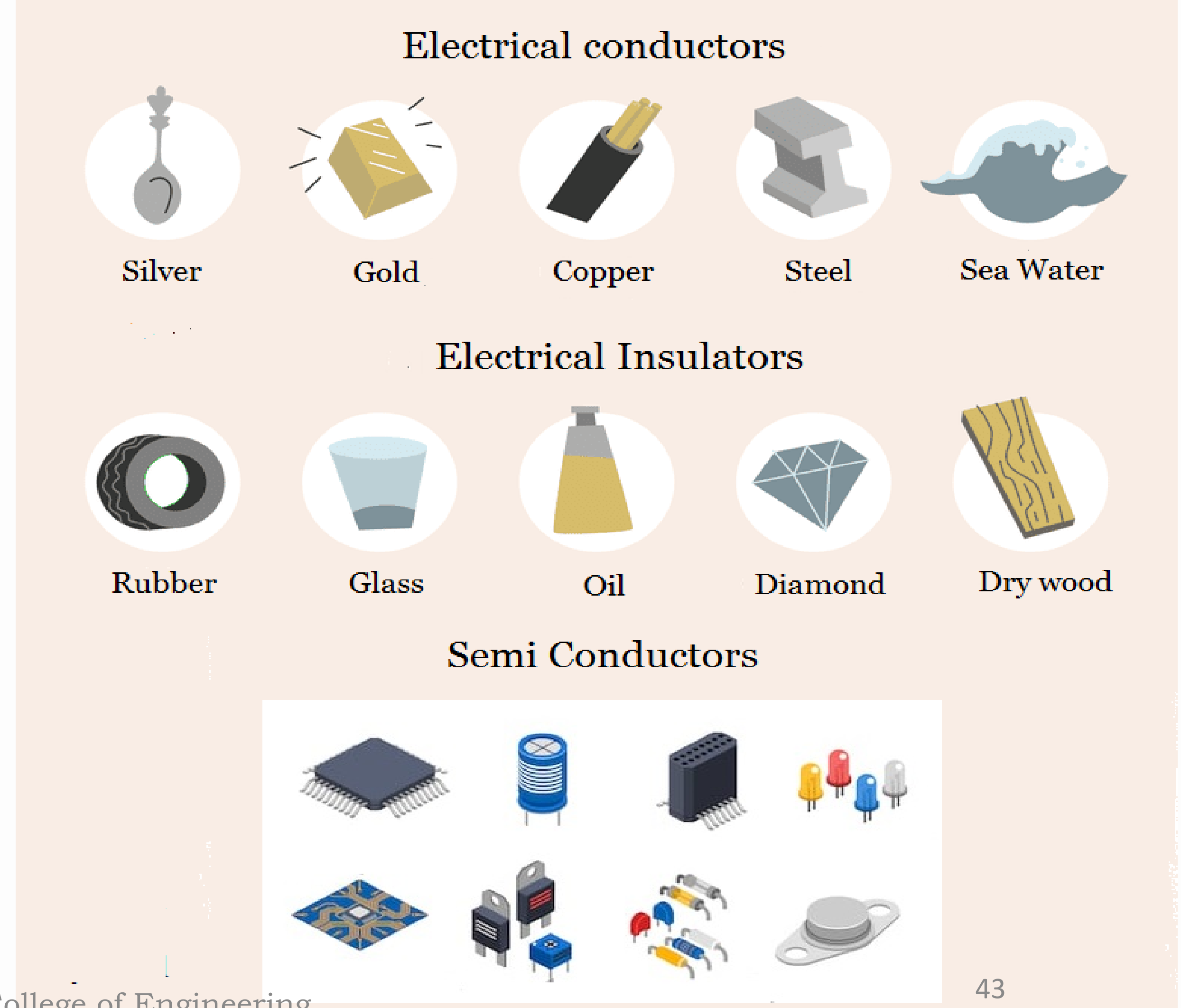
$$\sigma = \frac{1}{\rho}$$

Electrical and electronic conductivity

- **Dielectric strength** : Of an insulating material, the maximum electric field that a pure material can withstand under ideal conditions without breaking down (i.e., without experiencing failure of its insulating properties).

- **Conductors**
- **Insulators**
- **Semiconductors**





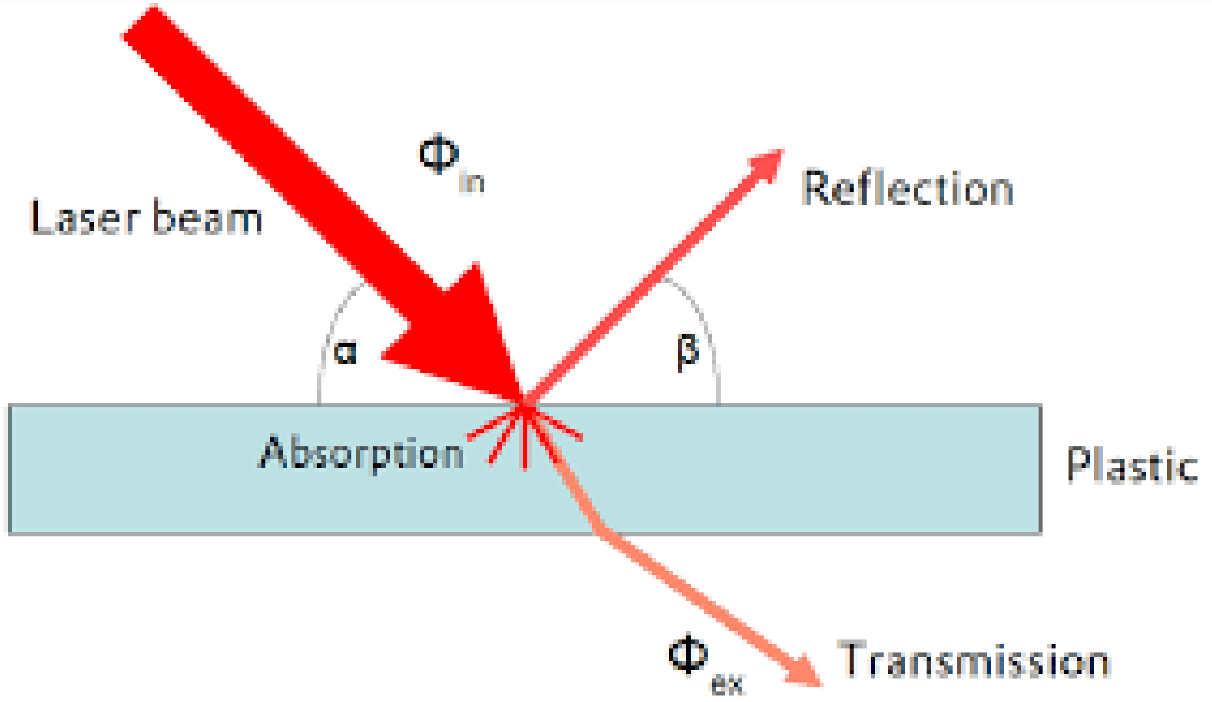
Optical Properties

- Optical property of a material is defined as its interaction with electro-magnetic radiation in the visible.

- Materials are classified on the basis of their interaction with visible light into three categories :

  - Materials that are capable of transmitting light with relatively little absorption and reflection are called ***transparent materials*** i.e. we can see through them.
  - ***Translucent materials*** are those through which light is transmitted diffusely i.e. objects are not clearly distinguishable when viewed through.
  - Those materials that are impervious to the transmission of visible light are termed as ***opaque materials***. These materials absorb all the energy from the light photons.

Optical Properties



Application of Engineering Materials

Ferrous Metals

- **Structural Purposes**
  Building structures, Concrete reinforcement.
- **Automotive**
  Chassis, engine parts, drive train and for body parts.
- **Marine**
  Ship hulls, structures and engines.
- **Defense**
  Tanks and weapons.
- **Consumer products**
  Appliances, vehicles, toys, utensils and tools.

Non-Ferrous Metals

- **Architectural purpose**
  Aluminum windows and doors.
- **Automotive**
  Aluminum engine blocks, copper wiring and magnesium wheels.
- **Marine**
  Brass and bronze fittings, bearings and propellers.
- **Defense**
  Brass shell castings
- **Consumer products**
  Electrical wiring, utensils, jewelry, electronics, etc.

Ceramic Materials

- **Automotive**
  Valve components, backings in crankshaft housing etc.
- **Mechanical equipment**
  High temperature and wear resistant cutting tools and pumps.
- **Electronics**
  High power electronic capacitor insulation.
- **Medical**
  Artificial bones and dental products.
- **Environment**
  Water treatment, waste recycling, processing of raw materials
- **Aerospace**
  Airframes, missile nose-cones, rocket nozzles

Composite Materials

- **Composite armors.**
  Carbon fibre armors
- **Sports**
  Sole of running shoe, shaft of arrow etc.
- **Aerospace**
  In many sectors of aerospace industry.
- **Transportation.**

Polymers

Different polymers are used for different purposes:

- **ABS**
  Refrigerator lining, garden equipment, toys, highway safety devices etc.
- **Acrylics**
  Lenses, transparent aircraft enclosure, outdoor signs etc.
- **PTFE**
  Anticorrosive seals, antiadhesive coatings, bearings, electronic parts etc.
- **Nylons**
  Bearings, gears, cams
- **Polyethylene**
  Flexible bottles, toys, battery parts, ice trays etc.
- **Epoxies**
  Electrical moldings, adhesives, protective coatings etc.

Semiconductor Materials

A very wide range of applications of semiconductor materials are established nowadays.