1 Introduction

1.1. MATERIAL SCIENCE :

Material science is a combination of two words **materials** and **science**. 'Material science' is the systematic study of different materials, their structures, properties and applications to engineering. The ultimate aim of engineering is the practical application of materials in the manufacturing of components and machines. To achieve this goal, selection of right material for the right job is the most important step. Selection of right material requires a deep knowledge of different materials. Material science deals with all these things. It is an applied science which is concerned with relationship existing between structures of materials and their properties. It concerns with the study of materials entirely for practical purposes.

In material science we confine our attention to solid materials, so this subject is related to solid state science. Engineering is the art of application of various conclusions and results drawn from pure sciences. Different types of materials are required to suit the specific requirements and applications in engineering. These materials are called engineering materials.

1.2. CLASSIFICATION OF ENGINEERING MATERIALS :

On the base of mode of occurrence engineering materials are classified as under :—

ENGINEERING MATERIALS

- METALS AND ALLOYS
  - FERROUS
    - (i) Wrought Iron
    - (ii) Mild Steel
    - (iii) Alloy steel
  - NON-FERROUS
    - (i) Copper
    - (ii) Aluminium
    - (iii) Zinc
- CERAMICS AND GLASSES (MgO, ZnO, concrete, cement, silica)
- ORGANIC POLYMERS
  - THERMO PLASTICS
    - (i) Polythene
    - (ii) Polyvinyl Chloride
  - MISCELLANIOUS
    - (i) Wood
    - (ii) Rubber
  - THERMO SETTING
    - (i) Phenolfurfural
    - (ii) Polystrenes

METALS AND ALLOYS : Metals are the polyerystalinc bodies consisting of great numbers of fine crystals (10^{-1} to 10^{-4} cm size). These crystals have different orientation with respect to one another. So metal is an elemental substance.

2 Properties of Materials

.1. INTRODUCTION :

Engineering is the art of application of various conclusions and results drawn om pure science to practical problems. Different engineering applications require fferent types of materials. It is essential that the design and production engineers ust be familiar with the properties of materials. Sound knowledge of the properties f materials is desired, in order to design and manufacture sound components and ructures and to avoide faliures during use. Metals and alloys have various physical, iemical, mechanical, electrical and other properties. A brief review of these properties ill follow in this chapter.

.2. CLASSIFICATION OF PROPERTIES OF MATERIALS :

The properties of materials are generally classified as under :—

PROPERTIES OF MATERIALS

IECHANICAL PROPERTIES	PHYSICAL PROPERTIES	THERMAL PROPERTIES	ELECTRICAL PROPERTIES	CHEMICAL PROPERTIES	MAGNETIC PROPERTIES
i) Strength	*(i)* Lustre	*(i)* Thermal conductivity	*(i)* Electrical conductivity	*(i)* Corrosion	*(i)* Permeability
ii) Elasticity	*(ii)* Colour	*(ii)* Coefficient of linear expansion	*(ii)* Resistivity.		*(ii)* Coercive forces
(iii) Ductility	*(iii)* Melting point		*(iii)* Temp. coeff. of Resistance		*(iii)* Hysterisis
(iv) Malleability	*(iv)* Density		*(iv)* Dielectric strength		
(v) Toughness			*(v)* Thermo electricity		
(vi) Brittleness			*(vi)* Super conductivity		
vii) Fatigue					
viii) Creep					
ix) Stiffness					
(x) Damping capacity.					

2.3. MECHANICAL PROPERTIES :

Mechanical properties can be described as the behaviour of materials under external loads. These are of great importance, particularly to the design engineers. Following are some mechanical properties.

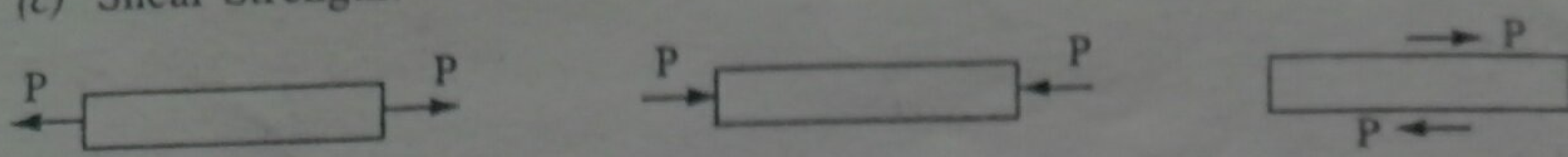
1. **Strength** : Strength of metals is the ability to withstand various forces to

which it is subjected. These are :—

(a) Tensile Strength.

(b) Compressive Strength.

(c) Shear Strength.



(a) Tensile strength (b) Compressive strength (c) Shear strength

Fig. 2.1. Different types of loading

Under different conditions of loading behaviour of metal is different. It depends whether the load is tensile, compressive or torsional and also depends on the rate of application of load i.e. impact, static or cyclic. It depends on temperature. of test also.

2. Elasticity : It is the property by virtue of which a body opposes permanent elongation.

A material is said to be perfectly elastic if the whole of stress produced by load disappears completely on the removal of load.

The relationship between stress and strain can be understood with the help of stress strain curve. It is a graph plotted between the different values of applied load (along ordiante) and the corresponding values of resulting strains (along abscissa) during the tensile test of material specimen. Following is the description of stress strain curve.

OP–Proportionality limit (Hooke's law obeys), OE–Elastic limit (Slightly higher than O.P.)

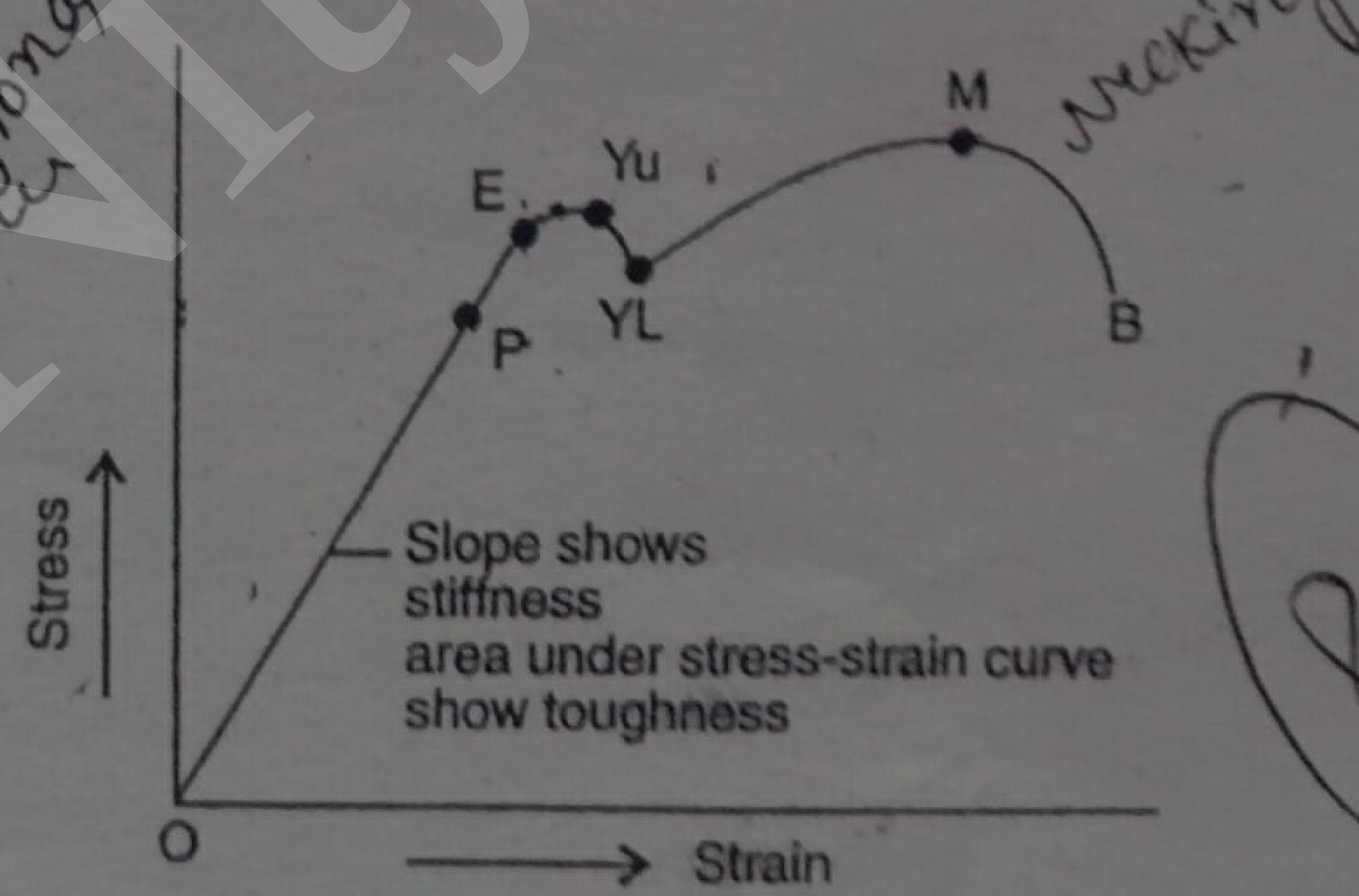


Fig. 2.2. Stress-strain curve for ductile material

Upto point E elongation takes place and disappears completely on removal of load

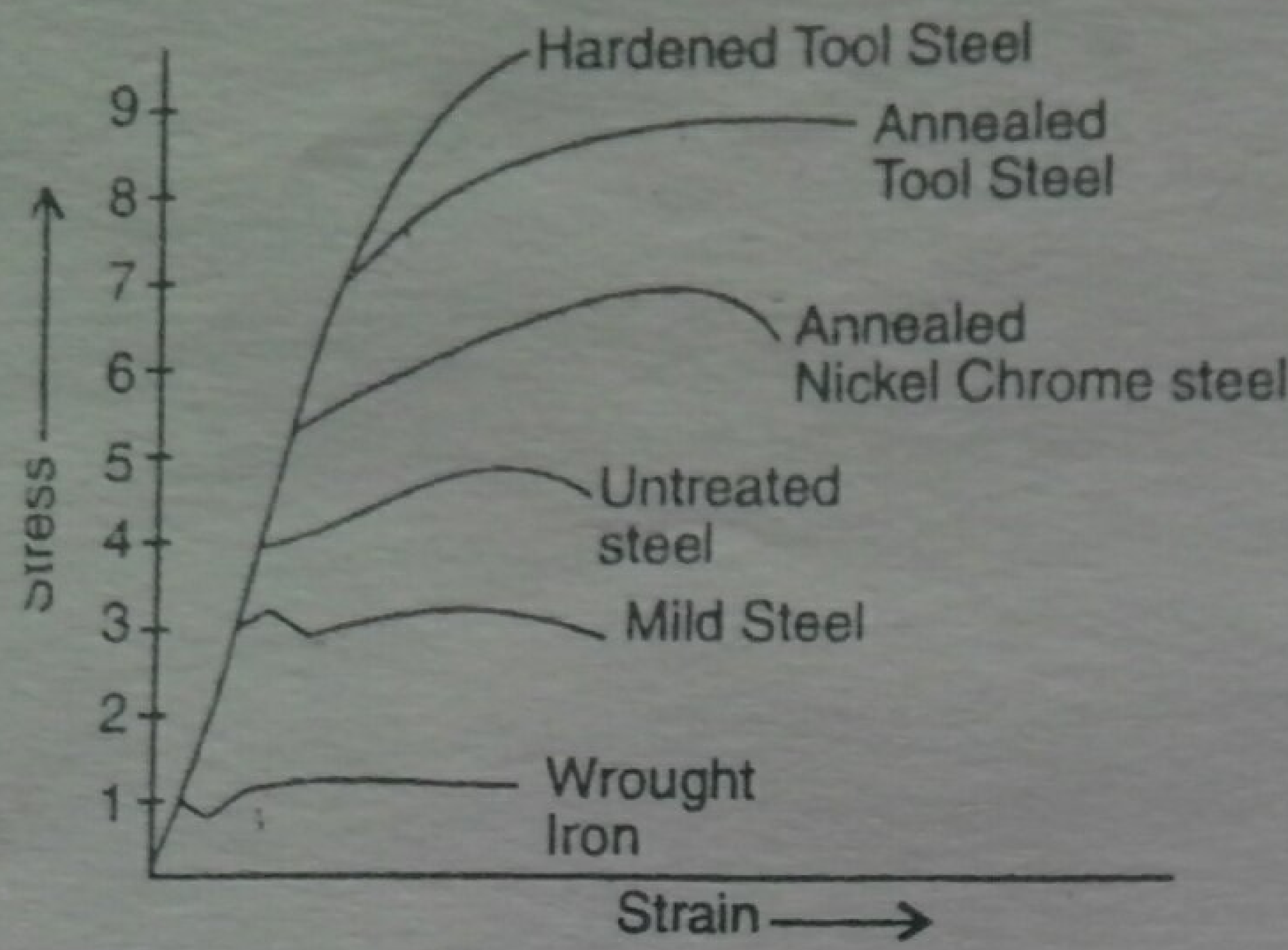
Beyond elastic limit there is plastic deformation and Yield point shows sudden extension.

Y_u–Upper yield point, Y_L–Lower yield point.

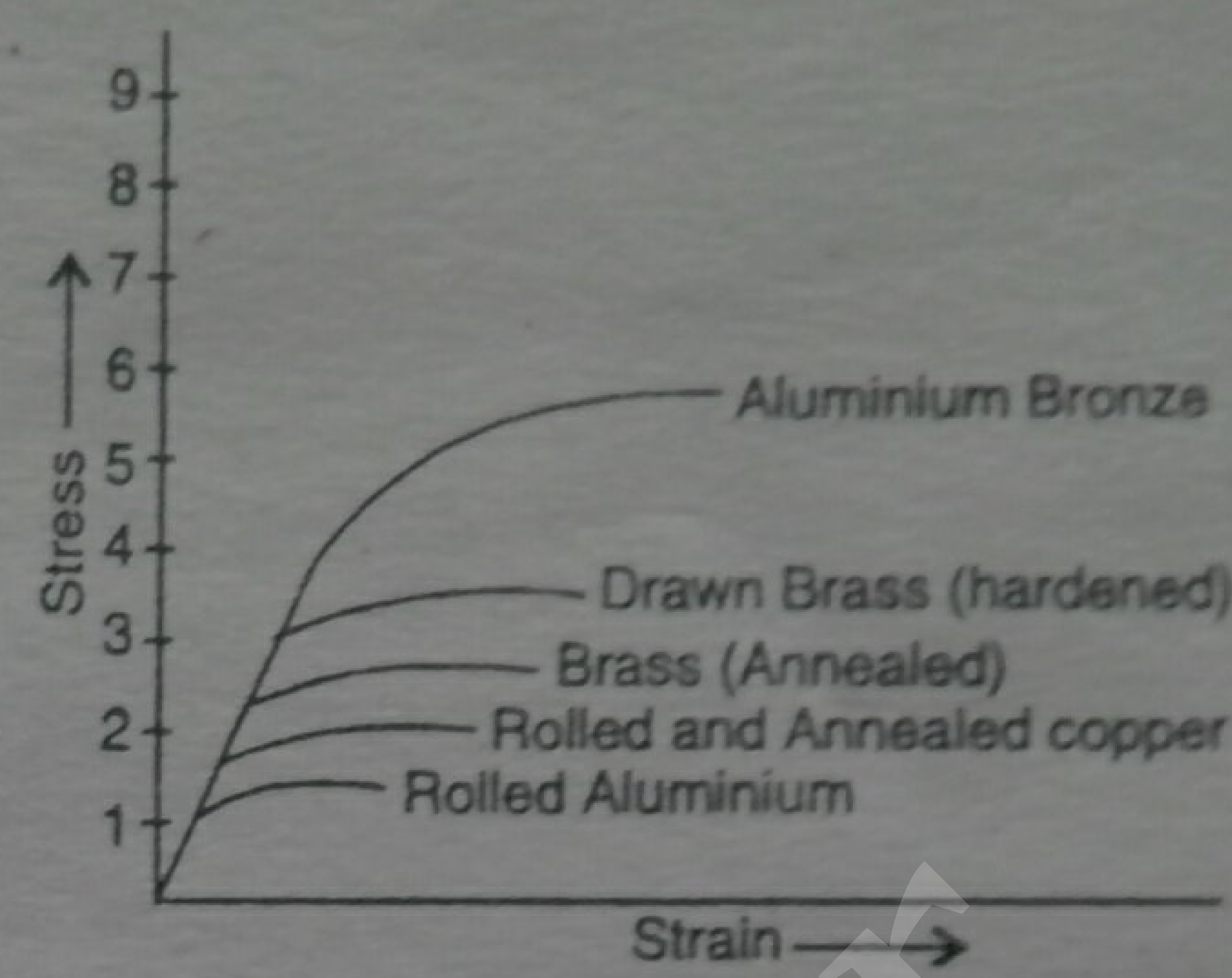
M–Maximum stress (ultimate tensile stress).

B–Breaking stress. (The specimen fractures at the point B.

Stress-Strain curve for different Metals



For Ferrous metals



For Non-ferrous metals

Fig. 2.3. Stress-Strain Curve

Young's modules (E) is the proportionality constant between stress and strain for astic materials. E is the indication of flexibility. Small value of E shows flexibility material and large value of E shows stiffness and rigidity of material.

Values of Young's modulus for different materials are shown in following table.

Lead $= 0.18 \times 10^6$ kg / cm^2	Copper $= 1.2 \times 10^6$ kg / cm^2
Tin $= 0.42 \times 10^6$ kg / cm^2	Wrought iron $= 1.97 \times 10^6$ kg / cm^2
Aluminium $= 0.72 \times 10^6$ kg / cm^2	Mild steel $= 2.1 \times 10^6$ kg / cm^2
Cast iron $= 0.98 \times 10^6$ kg / cm^2	Tungston $= 4.3 \times 10^6$ kg / cm^2

3. **Ductility :** It is the ability of a metal to withstand elongation. Due to this operty the metals can be drawn into wires. Ductility of a matérial is measured by ercentage elongation and the percentage reduction in area before rupture of the ecimen. Ductility of material is due to Plasticly. Ductility of material relates to its ility to be drawn into wires without rupture and without loosing much strength. uctility is a tensile characteristic. Ductility of a material is indicated by percentage ongation before necking during the tensile test of material.

Ductility of materials depends upon :—

(1) Hardness of material

(2) Heat treatment

(3) Toughness or Tenacity.

Gold is most ductile followed by platinum and silver. Ductility of some common aterials in decreasing order is given as under :—

Gold > Platinum > Silver > Iron > Copper > Aluminium > Nickel > Zinc > Tin.

4. **Malleability :** This is the property by virtue of which a material may be hammered or rolled into sheets without rupture. Malleability requires that a material must be plastic. Malleability is due to plasticity. Malleability can be defined as the ability of a material for being flattened into sheets without cracking. Malleability is a compressive characteristic. Malleability and ductility are indicative of the fact that atoms of material have capacity of slipping with respect to one another. Some common metals in decreasing order of malleability are as given :—

Gold > Silver > Aluminium > Copper > Tin > Platinum > Lead > Zinc > Iron.

5. **Hardness :** Hardness is the property of a material by virtue of which it resists indentation, penetration, machining, wearing or scratching. Hardness is determined by following numbers.

Hardness of some Typical Alloys.

S.No.	Alloy	Rockwell (B Scale)	Brinnle	Vickers
1.	Wrought iron	57	105	—
2.	Annealed Low Carbon Steel	55	100	—
3.	White Cast Iron	—	425	450
4.	Grey Cast Iron	98	230	240

(a) **Rockwell Hardness :** Rockwell hardness tester, measures the depth of indentation of a suitable penetration under certain conditions. Hardness number is read on the B-scale (if ball is used) and C scale (if conical diamond is used). The scales are calibrated in such a way that smaller penetration gives higher reading. The test parameters for both scales are as under.

(i) **B-Scale :** 1/16″ diameter Hardness steel bell loaded with 100 kg.

(ii) **C- Scale :** Diamond cone having apex angle of 120° and 150 kg is used for C scale.

The depth of Indentation gives the indication of hardness.

(b) **Brinnle Hardness :** This test is done with the help of 10 mm dia steel ball indenting against surface. The load is applied gradually and increased to the required value by hydraulic system. Standard time of loading is 15 sec. for ferrous metal and 30 seconds for non ferrous metals. Diameter of impression is measured and Brinell hardness number is calculated by the following formula :—

$$\text{B.H.N.} = \frac{2P}{\pi D\left[(D - \sqrt{(D^2 - d^2)}\right]} \text{ kg / mm}^2$$

Where :—

P—load applied in kg.

D—dia of ball and d-dia. of the indentation in mm.

(c) **Vicker's Hardness :** It employs a diamond pyramid under varying loads from 5 to 250 kg. Pointed diamond is pushed perpendicularly into the surface by a

ndard load. Hardness is represented by vickers pyramidal number (V.P.N.)

$$V.P.N. = \frac{1 \cdot 72P}{d^2}$$

Where,

P—Standard load in kg :

d—length of diagonal between the corners of rectangular impression.

6. **Toughness (Tenacity) :** Toughness is the strength with which the material opposes rupture. It is due to the attraction between molecules. This attractive force resists tearing. The area under stress strain curve shows toughness *i.e.*, the energy which can be absorbed by the material upto the point of rupture.

Toughness is also known as the ability of the material to resist impact. The value of toughness is very useful in the selection of a material where impact loads are frequently applied.

7. **Brittleness :** Lack of ductility is called brittleness. If a body breaks easily when subjected to shock it is said to be brittle. The brittle metal fractures without much elongation. A brittle metal posseses lesser toughness. A brittle metal develops cracks and breaks on the application of sudden load. To explain it, let us take the example of Cast iron, which is brittle but sufficiently strong material. It breaks suddenly as soon as stress strain curve deviates from straight line. Thus brittle materials should not be considered as lacking in strength. It only shows the lack of plasticity. It can be considered as the opposite of ductility.

8. **Fatigue :** Fatigue is the phenominon that leads to fracture under condition of repeated loading or fluacting load. The stress at which the material fails due to fatigue is called fatigue strength.

Fracture takes place under repeated or fluctuating stresses whose maximum value is less than the tensile strength of material under steady load. The fatigue faliure always shows a brittle fracture.

The phenominon of fatigue faliure is very important. The components which are subjected to repeated load, as motor shaft, gears, rotating machine parts, are designed by considering this phenominon. Under the conditions of dynamic loading in the metal part, at the point of stress concentration there is some dislocation movement. As a result of this a minute crack is developed. This crack grows and propagates with every cycle of loading, leading, ultimately to a brittle fracture.

Fatigue fracture is progressive. It begins from minute cracks that grow under the action of fluctuating stress.

Factors effecting fatigue :

1. Higher the surface finish of component, higher is the fatigue strength.
2. Compressive stresses finish increases the endurance limit.

Fatigue life curve (S–N curve) for ferrous and non-ferrous alloy is as shown in figure.

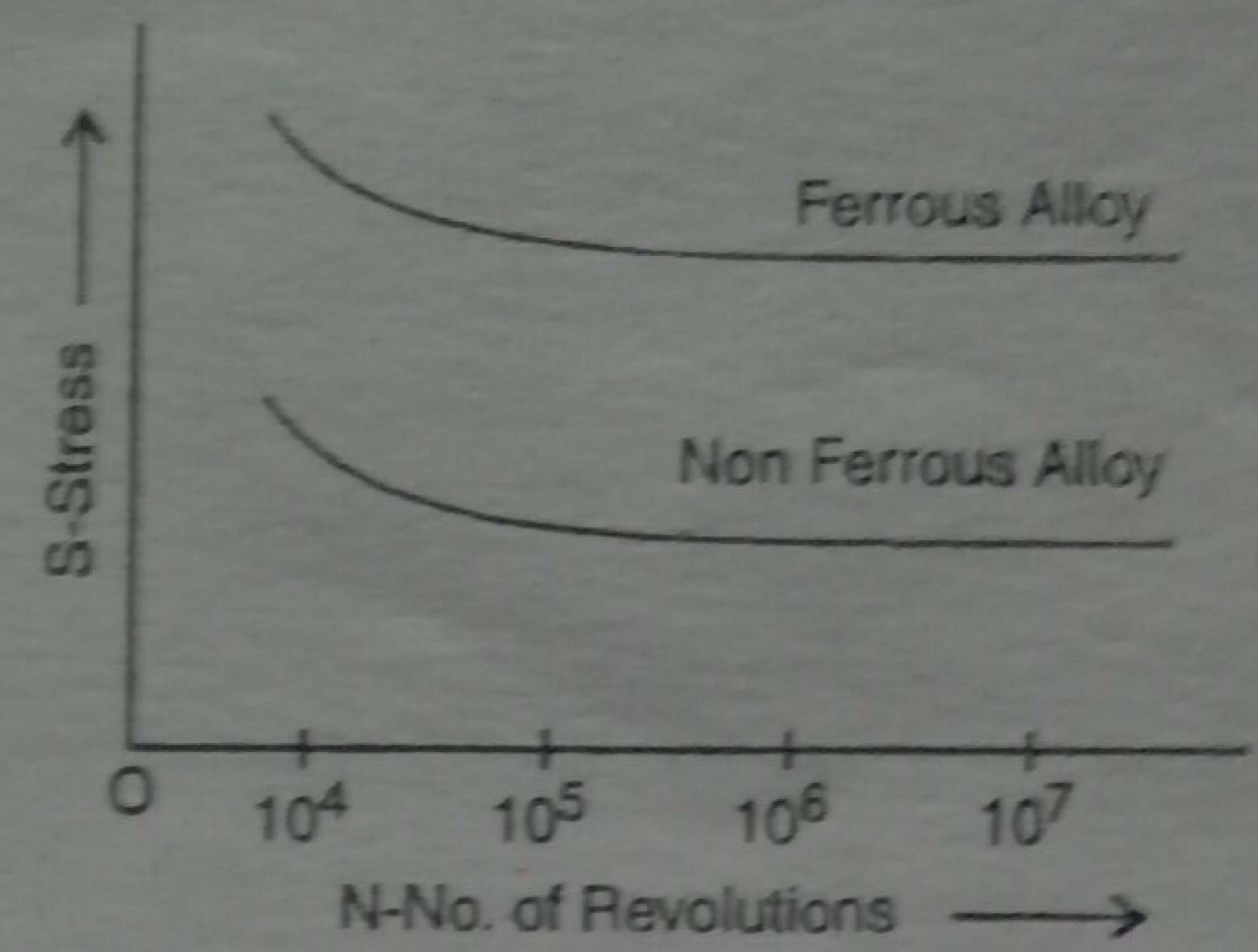


Fig 2.4. Fatigue life Curve

Endurance limit and Fatigue limit are defined as the maximum stress which can be applied repeatedly without causing failure. Endurance limit decreases by decarburization and increases by carburizing, hardening, nitriding or cold working of the surface. The value of the endurance limit for some common materials are as under :—

S.No.	Material	Tensile Strength kg / mm²	Endurance Limit kg / mm²		
			Bending	Compression	Torsion
1.	Free cutting steel (0.15%C)	40	18	13	10
2.	Medium Carbon steel (0.6 %C)	70	32	22	18
3.	Spring steel (0.7 % C)	200	60	42	34
4.	Brass (37 % Zn Rest Cu)	50	11	—	—
5.	Malleable Cast Iron	32	15	10	15

9. Creep : Creep is the slow plastic deformation of metal under constant stress or under prolonged loading. Creep is specially taken into consideration while designing, I.C. engines, boilers and turbines. Creep failure refers to the faliure of components under stress conditions.

Creep phenominon takes place under constant stress in the following three stages :—

(1) Primary stage

(2) Secondary stage

(3) Tertiary stage

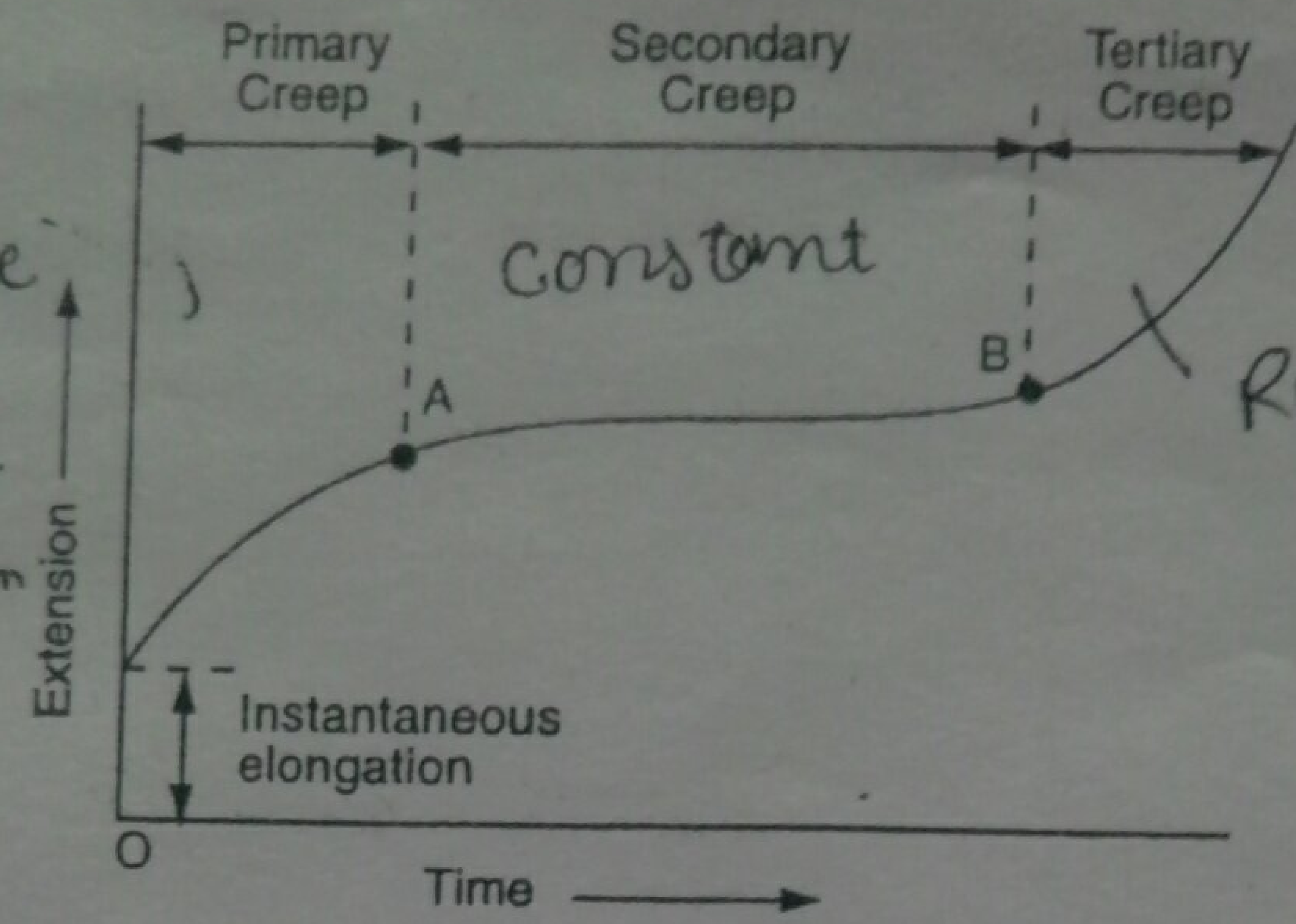


Fig. 2.5. Various Stages Showing Creep Formation

The first stage of creep is called primary creep. It represents a region of decreasing creep rate. In this creep resistance of material increases by virture of its own deformation. The second stage of creep is known as secondary creep. In this period creep rate is constant. It is also known as steady– state creep. The third stage of creep occurs at an accelerated rate. In this stage rate of extension accelerates and finally rupture takes place.

The creep strength of a metal is defined as the limiting stress below which creep is so slow that it will not result in fracture within any finite length of time. As the Temperature increases, creep strength and life is reduced.

Below Recrystallization temperature a fine grained steel shows greater creep resistance. Above recrystallization temperature, a coarse grained steel shows superior creep resistance. Creep resistance of steel below recrystalization temperature increases by adding nickle, cobalt and manganese. Carbide forming elements like chromium, tungston, molybdenum and vanadium also increase creep resistance.

Electric arc steel posseses better creep resistance than open hearth or bessemer steel. Steel produced by induction furnace posseses least creep resistance. Annealing of steel improves creep properties.

10. **Stiffness :** Stiffness of a material is the resistance offered to deformation, below the elastic limit. It is indicated by slope of stress strain curve. Greater the slope lesser is stiffness. The opposite of stiffness is called flexibility. The degree of stiffness of a material is indicated by the young's modulus if it obey the Hooke's law, by modulus of elasticity, in case of tensile and compressive stresses. Modulas of rigidity in case of shear stress and Bulk modulus in case of volumetric deformation.

It is needed in crankshafts, springs, beams, machine parts and structural members on which the extent of elastic deformation or deflection under load is significant. Under the constant load smaller the elastic deformation the stiffer is the material.

11. **Damping Capacity :** It is the ability of a material to absorb mechanical

engineering materials to prevent the large amplitude vibrations. Nickle is 100 times better then Aluminium in damping and vibrations. Grey cast iron is widely used for frames of machine tools due to very good damping capacity.

12. Resilience : Resilience is the capacity of materials to absorb energy with the elastic limit. On removal of load the energy stored is given off. The maximum energy which can be stored in body upto elastic limit is called proof resilience. Proof resiliency per unit volume is called modules of resilience. This property indicates the capacity of a material to with stand shock load and vibrations.

2.4. PHYSICAL PROPERTIES :

1. Lustre : It is the ability of a metal to reflect light when finely polished. It is also known as brightness of surface. Lusters of some metals/alloys are as under.

Aluminium, Antimony, Zinc, Gold,} Silver, Stainless Steel	—Bright
Chromium	—Shining
Tin, cobalt, manganese	—Metallic
Copper, Chilled cast iron	—Bright Metallic
Grey cast iron	—Dull

2. Colour : Many metals have specific colours that distinguish them from others. For example, brass and gold are yellow, silver is white, copper is reddish brown, aluminum is white, Tin is silvery white. Grey Cast Iron is greyish black.

3. Density : It is mass per unit volume of substance. The metals having more weight per unit volume are said to be of higher density. Metal having less wt. are of lower density. Aluminium, magnesium are light wt. metals.

Density of alloys is somewhere in between the density of parent metals.

4. Melting Point : Melting point of metal is that temperature at which a solid material is changed into liquid. Pure metal posseses a specific value of melting point.

Low melting point metals are used in safety devices like fuse plug, fuse wires, boiler safety devices etc.

Following are some common examples of low melting point metals and alloys :-

Lipowitz alloy (Bi—50%, Tin—13% , Lead = 27%, Cd = 10%)

Rose's metal (Bi—50%, Tin 22%, Lead 20%)

Necoton's alloy (Bi—50%, Tin 19%, Lead 31%)

High melting point metals are iron, nickle, tungston, chromium, maganese etc.

M.P. of some common metals are as under.

Aluminium	= 659 °C	Iron	= 1535 °C
Chromium	= 1615 °C	Cobalt	= 1480 °C
Molebidenium	= 2620 °C	Tungston	= 3410 °C
Tin	= 232 °C	Nickle	= 1452 °C
lead	= 327 °C	Copper	= 1083 °C
Silver	= 960 °C		

2.5. THERMAL PROPERTIES :

These are the properties which are the function of temperature or heat.

1. **Thermal Conductivity :** The property by virtue of which the flow of heat takes place from one end to another is called thermal conductivity. Thermal conductivity of a metal may be defined as the number of kilocalories of heat that would flow per second through specimen having cross section of $1m^2$ and 1m length, when the temperature gradiant is 1°C. If conductivity of copper is 100%, the relative conductivity of other metals are as under :—

Metal	Conductivity	Metal	Conductivity
Lead	8	Zinc	29
Tin	15	Magnesium	39
Platinum	16	Aluminium	62
Iron	17	Gold	72
Cobalt	18	Copper	100
Cadmium	23	Silver	106
Nickle	2		

2. **Linear Coefficient of Expansion :** It is defined as the increase in length per unit length for each degree rise in temperature. This property is considered when the metal is exposed for a change of temperature. For example engine piston, accurate fitting mechanism etc. All bodies generally expand on being heated. When a solid is heated it expands in all directions. The expansion in any direction is called its linear expansion, the increase in area is called surface or superfacial expansion and increase in volume is called volume or cubical expansion. Amount of thermal expansion depends on the interatomic forces.

2.6. CHEMICAL PROPERTIES :

Corrosion Resistance : Corrosion is gradual chemical or electrochemical attack on the metal by its surroundings. The metal is converted into oxide, salt, or other compound. Corrosive media includes air, industrial atmosphere, acidic, basic and salt solutions.

Due to corrosion a metal loses its strength, ductility and other useful mechanical properties. Corrosion depends upon many factors such as nature, composition and temperature of the corrosive agent, dissolved gases and impurities in the metal.

2.7. ELECTRICAL PROPERTIES :

1. **Electrical Conductivity :** It is the ability of a material to permit the flow of electricity. It is denoted by σ :—

$$\sigma = \frac{l}{R.A},$$

Where, σ—conductivity, R–Resistance of conductor,

l—length of conductor, A–Area of conductor.

Valency electrons which are free to move are the cause of electrical conductivity. As temperature increases electrical conductivity also increases.

2. **Electrical Resistivity :** It is the property of a material by virtue of which it resists the flow of electricity through it.

$$\text{Resistivity,} \quad K = \frac{R.A}{l} \text{ or } = \frac{1}{\sigma}$$

Causes of resistivity is resistance of material, presence of impurities, and stress in metal due to cold working.

3. **Temperature coefficient of Resistance :** It is used to specify the variation of resistivity with the temperature.

i.e.,

$$\alpha_T = \frac{\delta - \delta o}{\delta o} \cdot \frac{1}{T - T_o}$$

Where ; δ–Resistivity at temp. T

δ_o–Resistivity at temp. T_o

T and T_o are taken in °K.

4. **Dielectric Strength :** It is the insulating capacity of a material against high voltage. If the dielectric strength is more, the material can withstand sufficiently high voltage field across it before break down occurs and it conducts electricity.

5. **Thermo Electricity :** If two dissimilar metals are joined and the junctions are kept at different temperatures, a small voltage (in mili volt range) is produced, this effect is known as thermo electric effect.

The Reverse is called Peltier effect.

6. **Super conductivity :** Some metals and compounds lose their electrical resistance before absolute zero is reached and becomes superconductor. Super conductivity refers to the phenominon of sudden drop of resistivity of some metals at a temperature above absolute zero.

This temperature is called transition temperature. Transition temperature of some metals are given below :—

Titanium = 0.4° K   Niobium = 9.2 °K

Aluminium = 1.17 °K   NbH = 14 °K

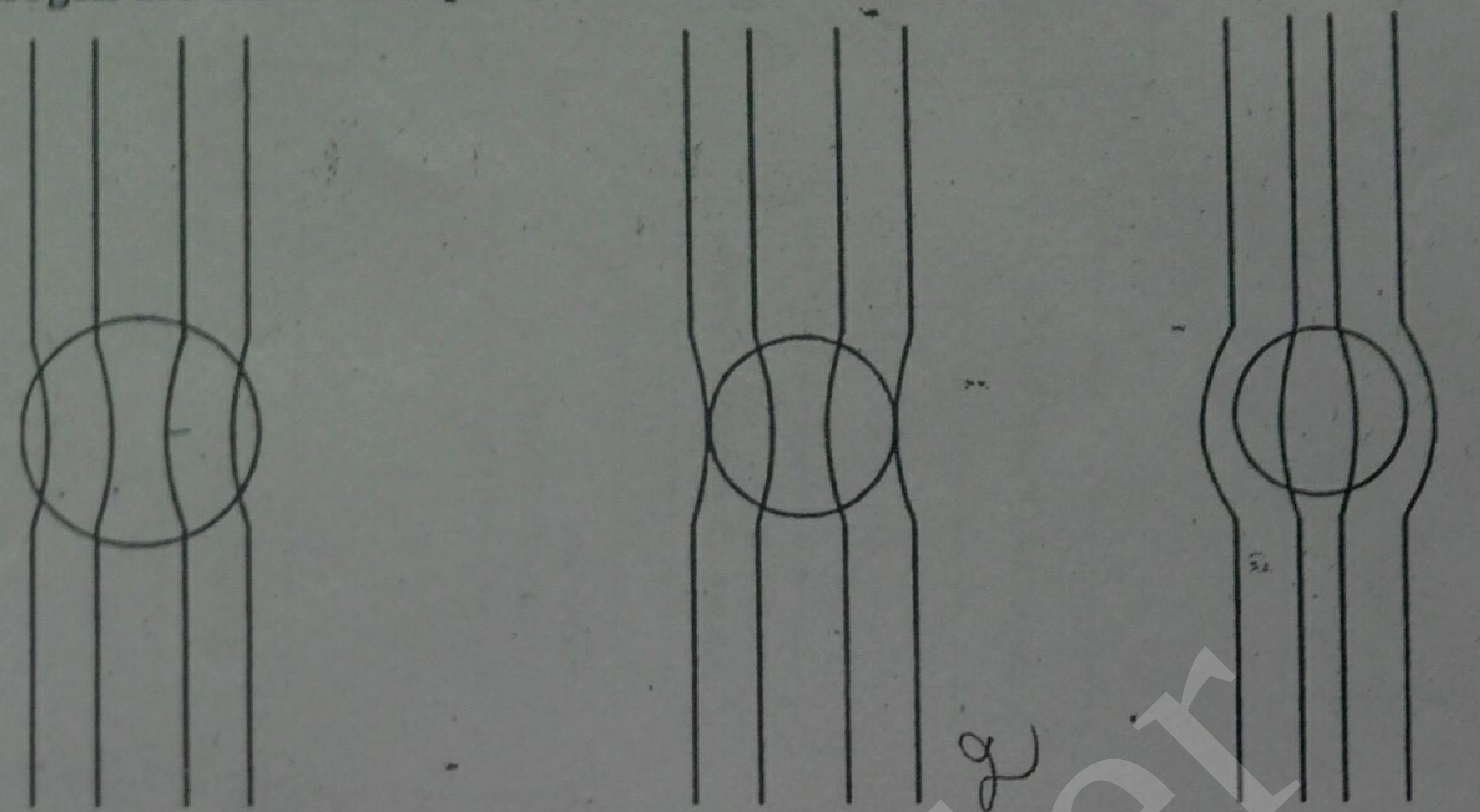
2.8. MAGNETIC PROPERTIES :

The materials in which the state of magnetisation can be induced are called magnetic materials. Such materials create a magnetic field in the surrounding space. The magnetic properties arise due to spin of electrons and orbital motion of electrons around the atomic nuclei. In several atoms the opposite spins neutralise one another but when there is an excess of electron spinning in one direction it produces magnetic field.

Ferro magnetic materials attract the lines of force strongly. These materials can form permanent magnets. Iron, nickle, cobalt are some examples.

Para magnetic materials attract the lines of force weakly. Aluminium, platinum and oxygen are some examples.

Diamagnetic materials repel the lines of force slightly. Bismuth, silver, copper and hydrogen are some examples.



(i) Ferro–magnetic *(ii)* Para–magnetic *(iii)* Dia–magnetic

Fig. 2.6. Magnetic Materials

Some important magnetic properties are :—

(1) Permeability, (2) Coercive force, (3) Hysteresis.

1. Permeability : It is the ratio of flux density in a material to the magnetising force producing the flux density.

$$\text{Permeability } \mu = \frac{\text{Flux density}}{\text{magnetising force producing flux density}} = \frac{B}{H}$$

Metals with high permeability are used for electromagnetic transformer cores etc. Hypersil (4 % Si) has permeability of 70,000. For good magnetic properties the grain size of metal should be large and work hardening strain should not be present.

2. Coercive Force : It is defined as the magnetising force which is necessary to neutralise the residual magnetism in an electro-magnet after the value of magnetising force becomes zero.

In the curve shown.

OC—Residual magnetism.

OD—Coercive force.

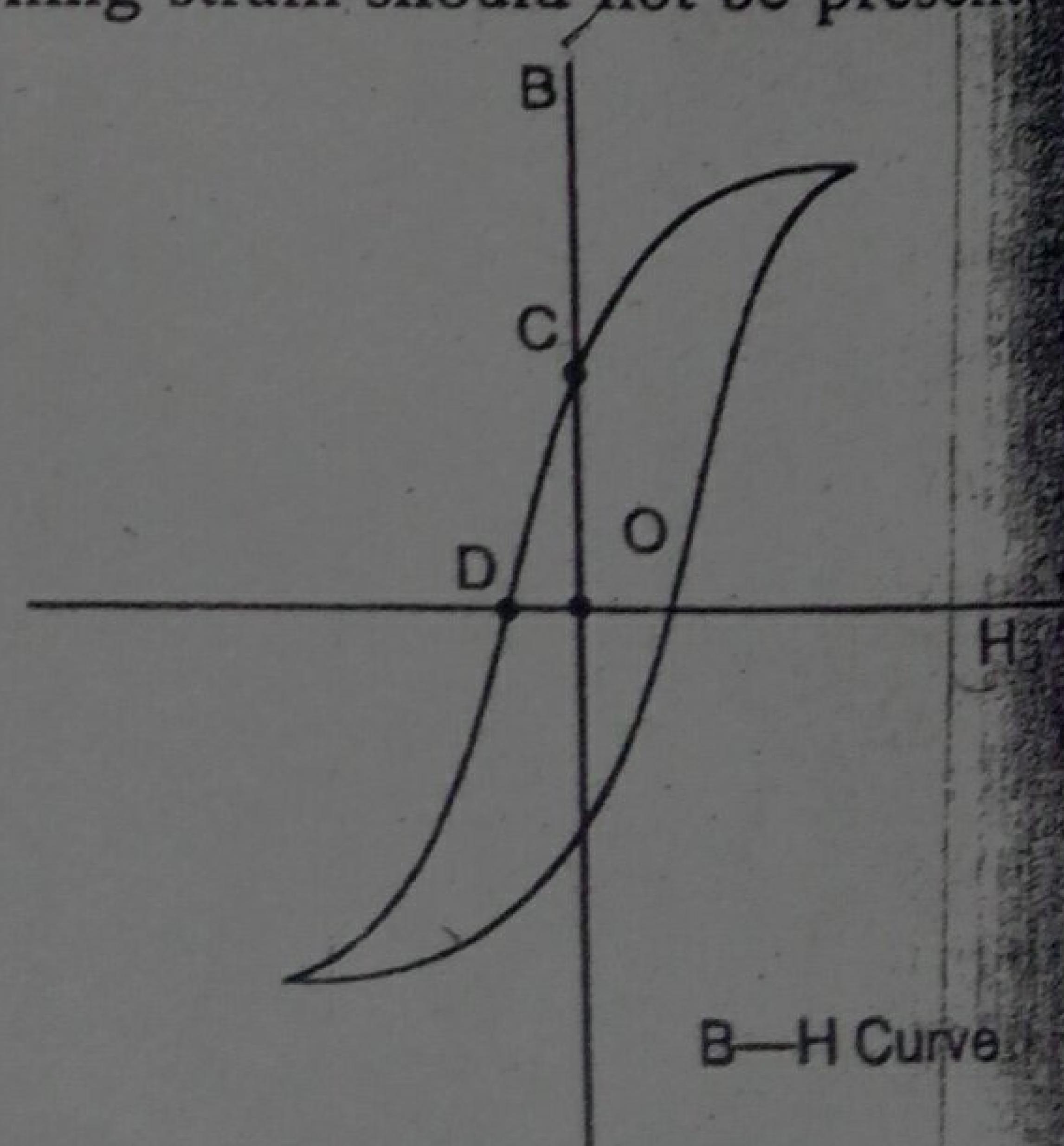


Fig. 2.7. B-H Curve

3. Hysteresis : It is the property of magnetic materials due to which the energy is dissipated in it on reversal of its magnetism. It may be defined as the lagging of magnetisation (or inductive flux density B) behind the magnetising force (M).

For every engineer a thorough knowledge of the manufacturing processes is essential. This would help him to appreciate the advantages, limitations and capabilities of the process. With such knowledge, he would be able to assess the feasibility of manufacturing a particular product from his designs. Further, he would be able to select proper processes, which would require the lowest manufacturing cost and would manufacture the product of requisite quality. A slight modification in design to suit the particular manufacturing process would also be possible.

Manufacturing processes are of two basic types:

(1) Processing Operations.
(2) Assembly Operations.

A processing operation converts a work material from one state of completion to a more advanced state which is closer to the shape of the desired final product. Thus, it changes the geometry, appearance or properties of the starting material and adds value.

An assembly operation joins two or more parts/components to create a new entity, which is known as assembly or sub assembly or some other term concerned with the joining process. Figure.1.2 shows the board classification of manufacturing processes.

1.6.1 Processing Operations

As shown in fig.1.2, these operations have three distinguished categories as follows:

(1) Shaping Operations
(2) Surface Operations
(3) Processes Affecting Changes in Properties

(1) Shaping Operations: Most of the shaping operations utilize heat or mechanical force or a combination of the two to effect a change in the geometry of input/work material. On the basis of the state of starting material, these processes are classified as follows:

(1) Casting Processes
(2) Powder Metallurgy
(3) Forming Processes
(4) Material Removal Processes

Casting Processes: These are the processes where metal is used in liquid form. Starting materials are heated sufficiently to transform it into a liquid state. Molten metal is poured into the mould cavity and allowed to solidify. The object after solidification is taken out from the mould. To manufacture a wide variety of

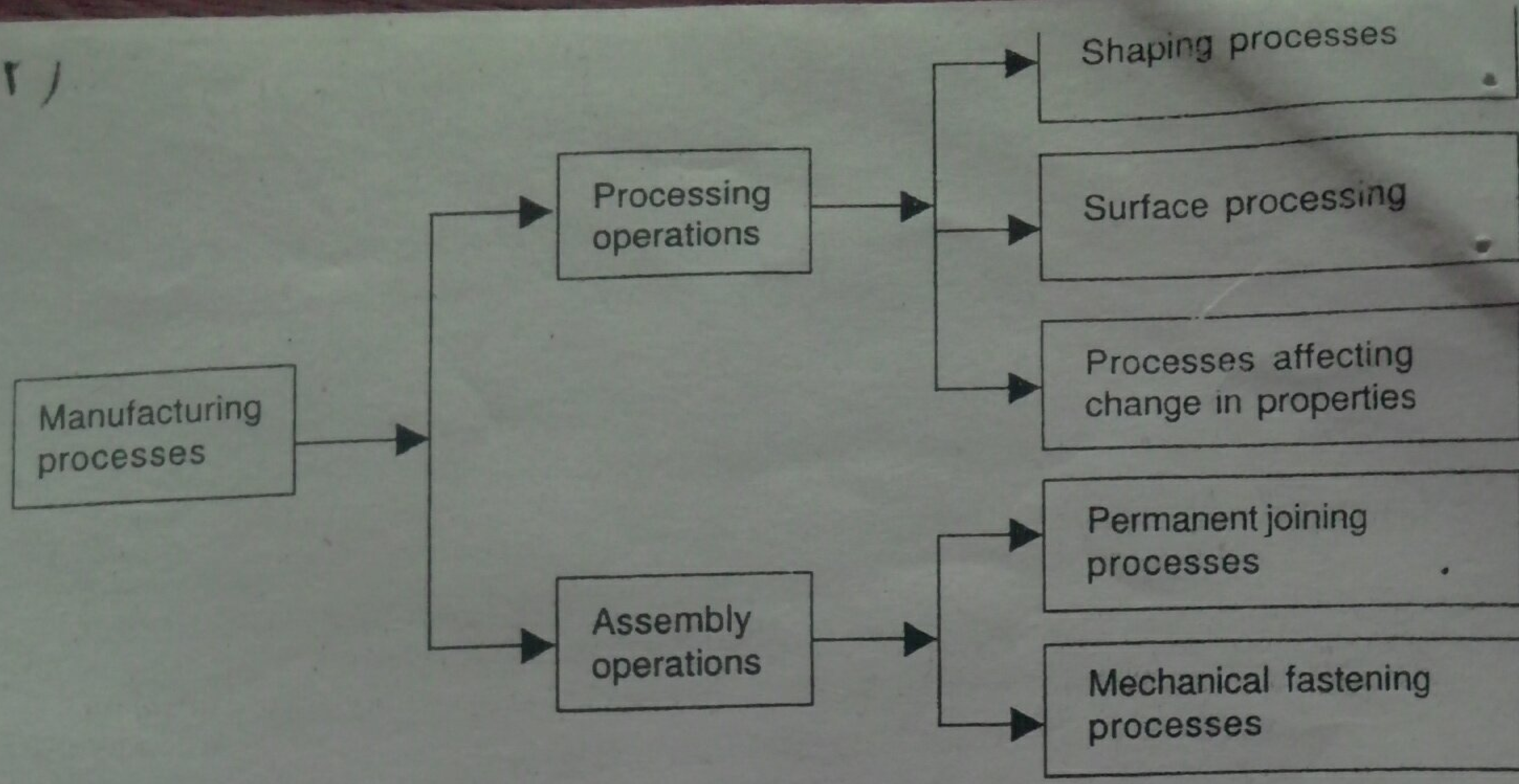


Fig. 1.2(a):

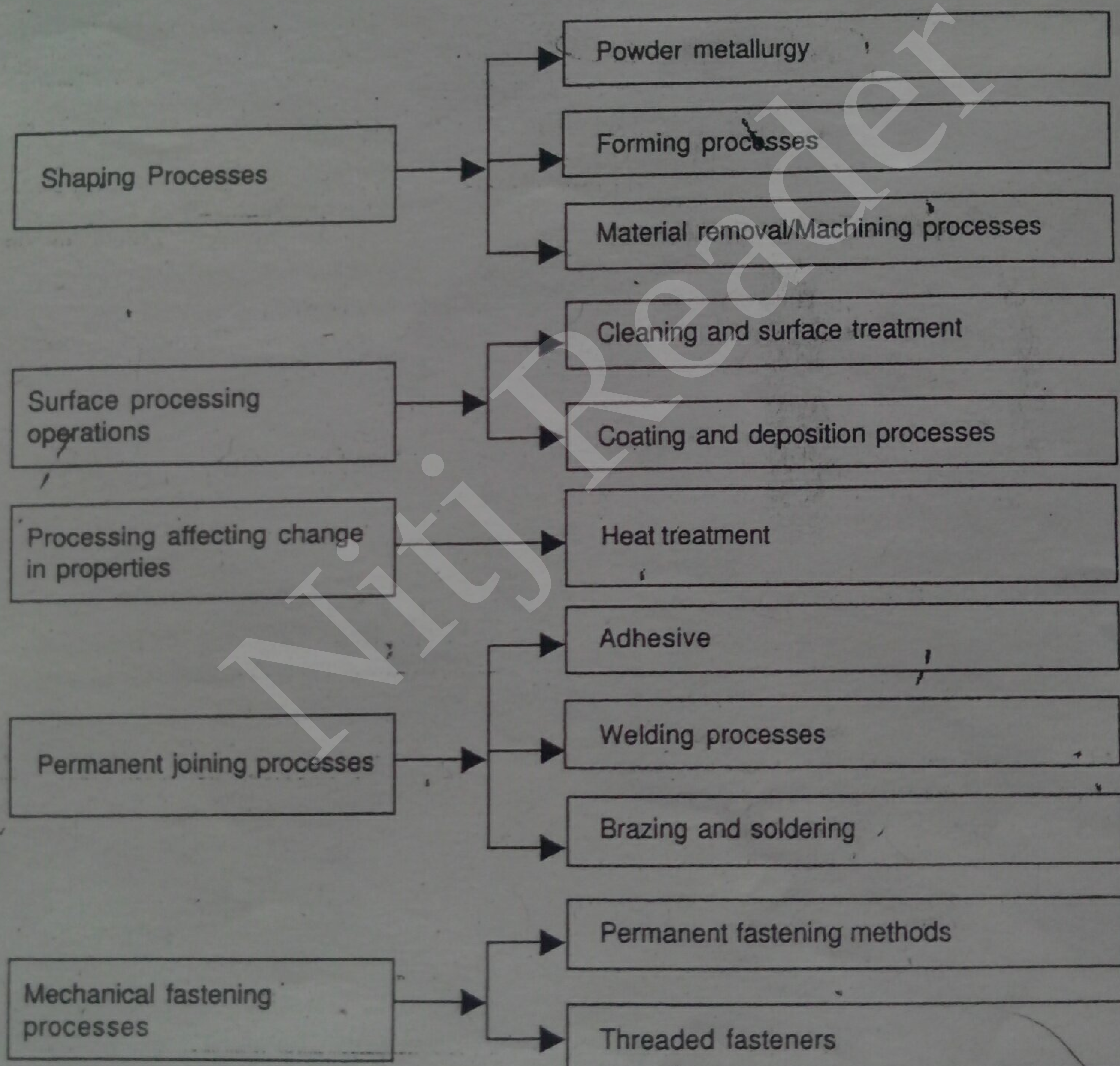


Fig. 1.2(b)

Fig. 1.2: Classification of Manufacturing Process

products, casting processes are utilized universally. Sand casting, [illegible] used as the refractory material, is the principal process among these operations. The process is equally suitable for batch and mass production processes. Some special purpose casting processes are as follows:

(1) Permanent Mould Casting
(2) Centrifugal Casting
(3) Die Casting
(4) Shell Mould Casting
(5) Precision Investment Casting
(6) Plaster Mould Casting

Powder Metallurgy: Items/goods are produced by pressure and heat in powder metallurgy. Usually, the two stages i.e. of pressure and heating are separate and are termed as compacting and sintering stages respectively.

Forming Processes: These processes are faster and have minimum material wastage in which the metal is heated to a temperature slightly below the temperature of solids and soon after, a huge force is applied so that the material flows and takes the requisite shape. The processes are generally economical and in some cases, improve the mechanical properties also.

Some commonly used forming processes are:

(1) Extrusion
(2) Rolling
(3) Forging
    (i) Drop forging
    (ii) Press forging
    (iii) Up set forging
(4) Wire drawing
(5) Sheet Metal working
(6) Thread rolling

Material Removal Processes: The principle used in all these processes is to generate the requisite surface by providing suitable relative motion between the work piece and the tool. Material removal is usually the most expensive manufacturing process because more energy is consumed and lot of material goes as waste in the form of chips. In view of the achievement of good dimensional accuracy and good surface finish, these processes are widely utilized. Some of the matching processes normally used are:

(1) Turning
(2) Milling
(3) Shaping and palming
(4) Drilling
(5) Grinding
(6) EDM
(7) ECM

(8) Broaching
(9) Ultrasonic machining

(2) Surface Processing Operations:
These operations include:

(1) Cleaning
(2) Surface treatments
(3) Coating and thin film deposition processes.

Cleaning means removal of dirt, oil and other contaminants from the surface by chemical and mechanical processes.

Surface treatments means mechanical working operations such as sand blasting, and physical processes like diffusion and ion implantation. During the coating, material is applied to the exterior surface of the work piece. Thin film deposition operations include physical as well as chemical vapour deposition in order to form extremely thin coatings of various materials. Common coating processes include anodizing of aluminum, electroplating, organic coating and porcelain enameling.

Coating operations are most commonly done in case of metal products/ parts and rarely in case of ceramics and polymers. The main reasons to apply coatings to the surface of the product are:

(1) Corrosion Protection
(2) Better look, colour and appearance
(3) Wear resistance
(4) Preparation for further processing

(3) Processes Affecting Change in Properties: These processes are employed to improve physical and mechanical properties or impart certain specific properties to the work material to make it suitable for particular operations or uses. Most of the physical properties like hardening, softening and grain refinement etc. require particular heat treatment, not only affecting the physical characteristics but in a majority of the cases, providing a marked change in the internal structure of the metal. A few prominent operations among these are as follows:

(1) Heat Treatment
(2) Shot Peening
(3) Cold Working
(4) Hot Working

1.6.2 Assembly Operations

The second category of basic manufacturing operation is the assembly, in which two or more separate parts/components are joined together to create a new entity.

components of the new entity are connected together either permanently or impermanently.

Permanent joining operations commonly used are:

(1) Welding
(2) Soldering
(3) Brazing and
(4) Adhesive bonding

The joints obtained by these methods cannot be easily disconnected.

Semi permanent mechanical assembly techniques are available to fasten two or more components together in a joint that can be conveniently disassembled. In this category, the use of *nuts and bolts screws* and other *threaded fasteners* are important traditional techniques.

Other mechanical assembly methods that form a more permanent connection include riveting, press fitting, expansion fits and shrink fitting.

1.7 PRODUCTION SYSTEMS

A manufacturing firm must have some production systems that allow it to operate effectively and efficiently to accomplish its type of production.

These are composed of people, equipment/machines and procedures/methods designed for the combination of materials and processes that establish/constitute firm's manufacturing operations. Production systems can be broadly divided into following two categories:

(1) **Production Facilities:** Production facilities are concerned with the physical equipment and the arrangement of equipment in the factory.

Manufacturing support systems are the procedures that are utilized by the organization/enterprise to manage production and tackle the technical as well as organization of supplies and services problems encountered in ordering materials, ensuring that the products meet quality standards and work keeps moving through the plant/factory. So people make these systems work. In general, direct labour/manpower are responsible for operating the machines/equipment and the managerial staff are responsible for manufacturing support.

(2) **Manufacturing Support Systems:** These facilities consists of the plant, production equipment, material handling equipment etc. Facilities also include the way the machines are arranged in the plant i.e. plant layout.

It is worthwhile to refer here the type of production since the choice of type of production determines the machine requirement, organizational set up and to a large extent, planning and inventory subsystems. All this is in view of the attempts to organize each of plants/factories in the most efficient manner so as to achieve the goals of the organization.

1.7.1 Types of Production Systems

The production systems vary from factory to factory and from product to product. However, one of the most important issues is production volume that is proposed to be produced. The most common types of production systems are:

(i) Job order production
(ii) Batch order production
(iii) Continuous production

Job Order Production: This type of production system is characterized by the low production volume which is related with the manufacture of products to meet the specific consumer requirements. This is usually concerned with special projects, special equipment or machinery to perform specialized and specific tasks—large turbo generators, boilers, processing equipment, material handling equipment and ship building etc. are examples of this production group.

Job order production can be of following three types as per regularity of manufacture i.e:

(1) Small number of products produced once only.
(2) Small number of pieces produced intermittently when the need arises.
(3) Small number of pieces produced periodically at known time intervals.

There is little scope for improvement of manufacturing technique, if the order is to be executed once only by introducing intricate method studies, special tools, jigs and fixtures etc. However, if the order is of a repetitive nature, tooling and jigging as well as special purpose inspection gauges should be carefully considered to reduce unproductive time and to accelerate work oriented activities.

Batch Order Production: This type of production is suited for medium volume lot of the same variety either to meet a specific order or to satisfy the demand of the market. When the production of a specific batch is terminated, the plant facilities are available for the production of other similar products as per market demand.

Batch order production can be of the following types:

(1) A batch produced only once.
(2) A batch produced repeatedly at irregular intervals when the need arises.
(3) A batch produced periodically at known intervals to satisfy continuous demand.

Batch production is a very common feature in the industry. Machine tool manufacturing, press work, forging and casting processes, some glass manufacturing and chemical processes very often operate on batch basis.

Continuous Production: This type of production is the specialized manufacturing of identical products/goods for which the equipment/machinery is fully engaged. Production rate is generally very high. Continuous production is justified only better life with the use of manufactured products. The manufacturing process forms a vital ingredient for various products such as plant and machinery that is needed in various disciplines of engineering, e.g. electrical, electronics, chemical etc.

A detailed knowledge of the manufacturing processes is thus essential for every engineer. He will be able to appreciate the process capabilities, advantages and limitations. This in turn would help him in the proper design of the product as per demand in the market. Further, he would be able to assess the feasibility of manufacturing the requisite design, select the appropriate process requiring minimum manufacturing cost and of the desired quality from the different/alternative techniques or processes available. If required, he may incorporate slight modifications to suit the selected manufacturing process or make his own choice.

1.1 DEFINITION OF MANUFACTURING

Manufacturing can be defined in two ways in the modern context i.e. technologic and economic. Technologically, manufacturing is the application of physical and chemical processes for changing the geometry, characteristics and/or appearance of a given input material to produce parts or products, the assembly involving many parts to make products is also included in manufacturing. The processes to accomplish manufacturing involve a combination of machines/tools , man power, power/energy and methods as represented in fig.1.1 (a). Manufacturing is accomplished as a sequence of operation. Performance of each operation brings the basic/input material closer to the desired final state.

Economically, manufacturing means the transformation of materials into items/goods of greater value by way of one or more processing and/or assembly operations as shown in fig. 1.1 (b). The meaning of greater value is that manufacturing adds value to the material by altering its shape or characteristics. The material has been made more valuable by virtue of the manufacturing operations performed on it. For example, when plastic is moulded into the complex geometry of furniture e.g. lawn chairs, it is made even more valuable.

1.1.1 Manufacturing Industries and Products

As discussed earlier, manufacturing is an important activity, but it is performed by various enterprises/organizations as a commercial activity for the purpose of financial gains and customer satisfaction associated with different other aspects of society. The type of manufacturing carried out by an enterprise/company is concerned with the product it makes. A type of relationship exists between the type of manufacturing industries and their products. Their produce or make is discussed as follows:

Manufacturing Industries: Industry means enterprises and organizations that are able to produce or supply goods/products and services. Industries can be classified* as follows:

* As per the international standard Industrial classification.

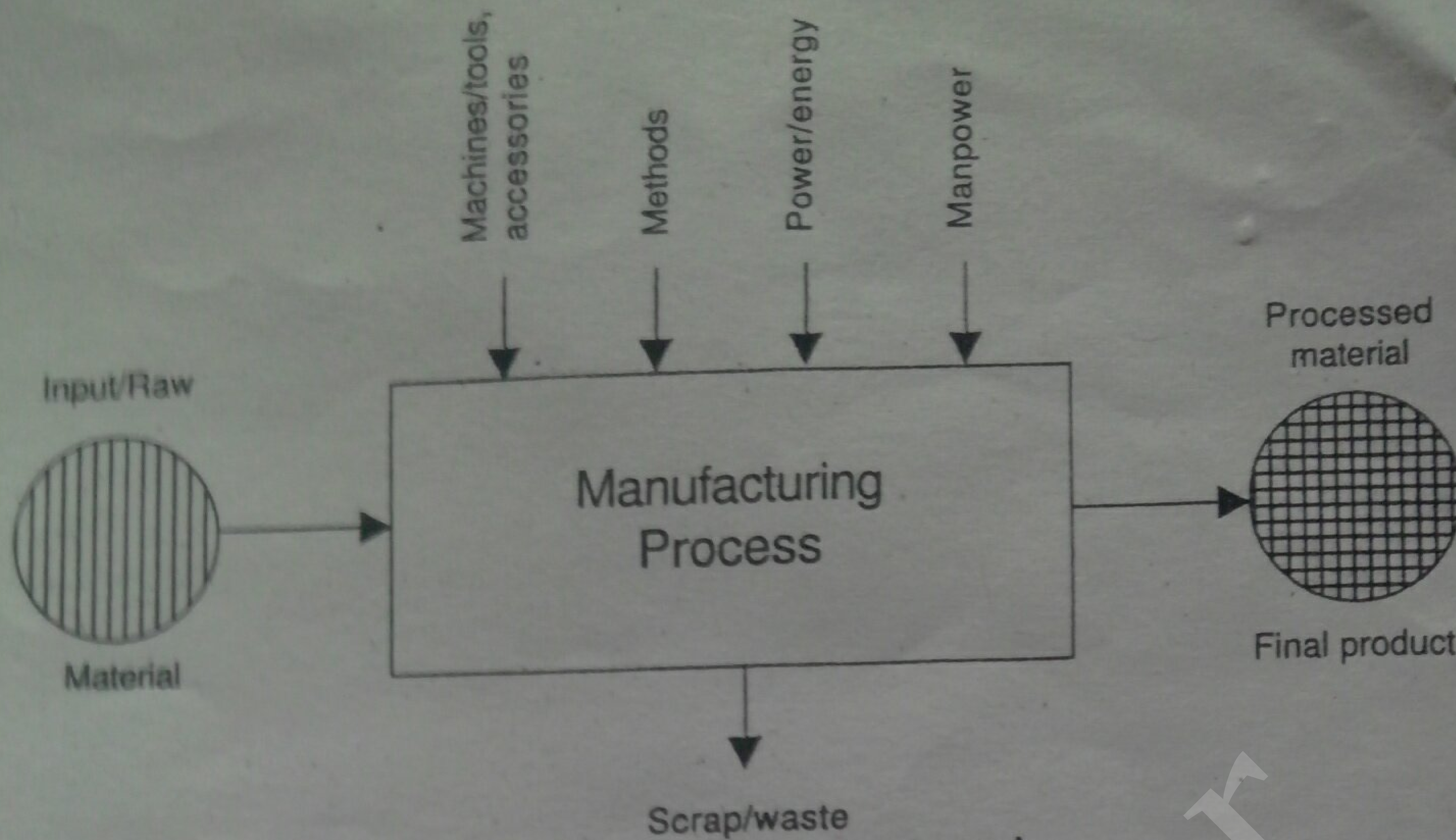


Fig. 1.1(a): Manufacturing as a Technical Process

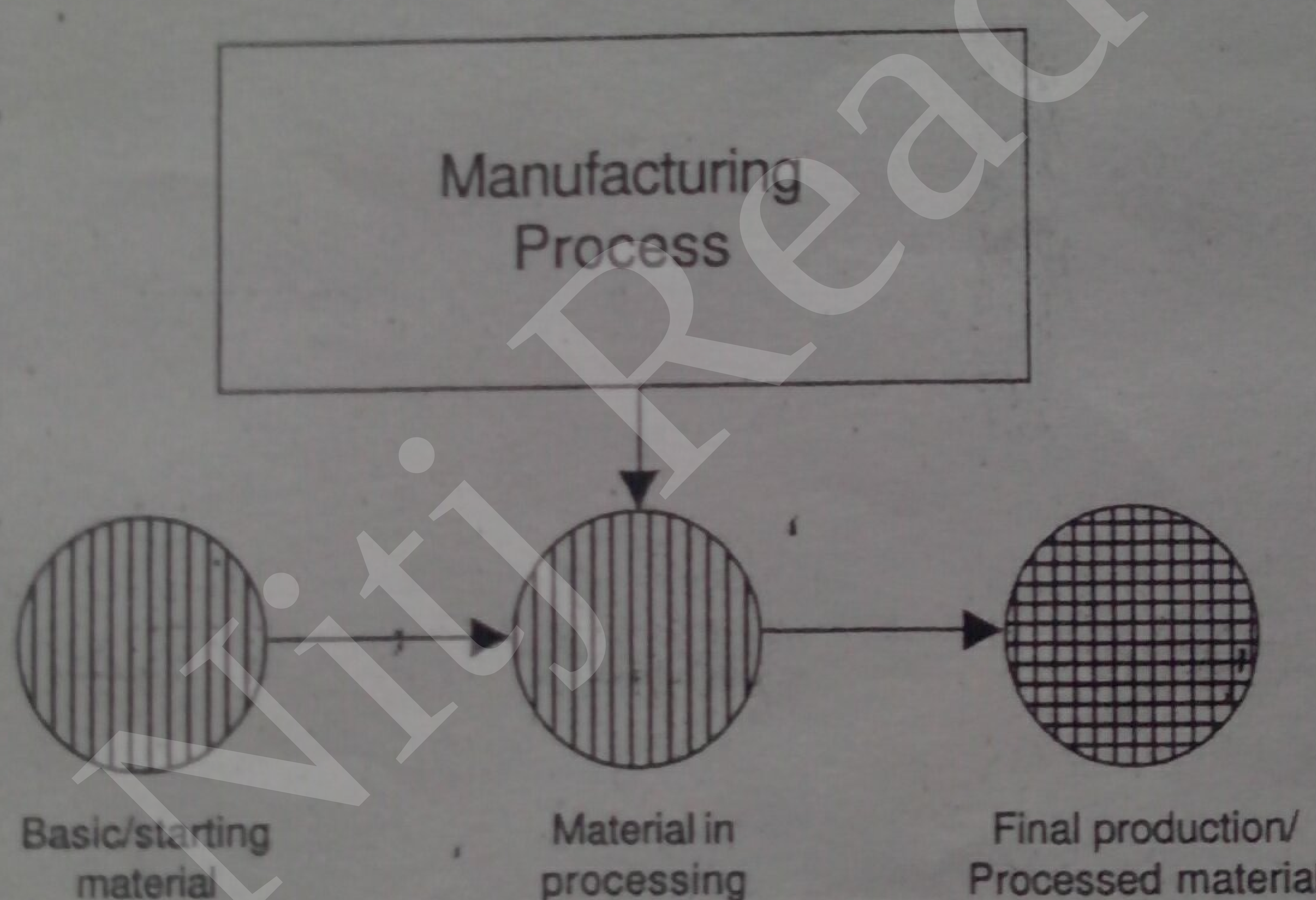


Fig. 1.1(b): Manufacturing as an Economical Process

The words production and manufacturing are often interchangeably utilized.

(1) **Primary Industries:** Those industries that exploit and cultivate natural resources such as agriculture, forestry, petroleum and mining etc.

(2) **Secondary Industries:** Those industries that utilize the output of primary industries to convert it into consumer and capital goods. The principal activity in this case are manufacturing industries such as automotives, computers, electronics, glassware and many others but it also includes construction and power utilities.