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Introduction to Engineering Materials and Their Properties

0.1. MATERIALS

In modern society we are surrounded by an amazing variety of materials. Most of the materials are solids that have been modified from their natural states to make them more suitable for practical applications. Human beings have the ability to use and develop materials to satisfy our human requirements. Nowadays we use many types of materials, transformed in many different ways, to satisfy our requirements for housing, heating, furniture, clothes, transportation, entertainment, medical care, defense and all the other trappings of a modern, civilised society.

A material is defined as a substance (most often a solid, but other condensed phases can also be included) that is meant to be used for certain applications.

There are many materials around us—they can be found in anything from buildings to spacecraft. Materials can generally be divided into two classes:

- Crystalline
- Non-crystalline.
- The traditional examples of materials are metals, semiconductors, ceramics and polymers.
- New and advanced materials that are being developed include nanomaterials and biomaterials etc.

Material Science is a scientific discipline which establishes the relation between the structure, properties of the materials and the processing done on them.

0.1.1. Engineering Materials

Almost every substance known to man has found its way into the engineering workshop at some time or other, hence named as engineering materials.

0.2. HISTORY OF MATERIAL ORIGIN

The materials which people use have such an impact on their lifestyles that historical eras have been named after those materials. These are referred to as the Stone Age, Bronze Age and the *Steel Age*.

All types of materials are included in the materials engineering, including ceramics, magnetic materials, and biological materials. The basic knowledge of the materials engineering started in the 19th century when it was proved that the thermodynamic characteristics related to the atomic structure are affected by the physical properties of a material. A major breakthrough in the understanding of materials occurred in the late 19th century, when the American scientist *Josiah Willard Gibbs* demonstrated that the thermodynamic properties related to atomic structure in various phases are related to the physical properties of a material.

<i>Early humans</i>	<i>Stone age</i>
4000–2000 BC	Copper age
2000–1000 BC	Bronze age, <i>i.e.</i> (Cu, Sn) alloys invention of metallurgy
1000–1 BC	Iron age

0.2.1. Timeline of Materials Technology

Before Common Era

- **29,000–25,000 B.C.E.:** First ceramic appears
- **8000 BC:** First use of Cu, in the area we presently call Iraq. Found in rock formations in the metallic state, dug up and beaten into shape, to form tools, ornaments, etc.
- **5000 BC:** Pottery made and Cu extracted from its ore. These two materials technologies are related. High temperatures are needed to extract metal from ore, Pottery ovens, properly ventilated, provided the needed temperatures. About this same time gold was discovered, dug up out of the ground and beaten into various shapes
- **3500–3000 BC:** Copper metallurgy is developed and copper is used for ornamentation. Hardening of Cu with Sn. Beginning of the Bronze Age. The alloy is considerably stronger than the pure metals.

- **2000 B.C.:** Bronze is used for weapons and armor
- **1600 B.C.:** The Hittites develop crude iron metallurgy
- **1500 B.C.:** Production of metallic iron from its oxide ore. This requires temperatures considerably higher than extraction of Cu and requires charcoal as a reducing agent. This was first done by the Hittites in present-day Turkey. Fe has important advantages over Cu: It is much more common and cheaper. The Fe-C alloy is much harder and stronger than Cu alloys so one can produce better tools and weapons with sharper edges. Knowledge of Fe smelting was so valuable that the Hittite kings apparently restricted the export of Fe weapons and kept secret their iron working techniques. The Iron age led to many changes in society. With a sharp Fe axe one could chop down trees more easily for building wooden houses. This led to the deforestation of much of Europe
- **1000 B.C:** Glass production begins in Greece and Syria
- **20s B.C:** Roman architect Vitruvius describes low-water-content method for mixing concrete

First millennium

- **700s:** Porcelain is invented in China

Second millennium

- **1448:** *Johannes Gutenberg* develops type metal alloy
- **1450s:** *Cristallo*, a clear soda-based glass is invented by Angelo Barovier
- **1590:** Glass lenses are developed in the Netherlands and used for the first time in microscopes and telescopes

Eighteenth century

- **1738:** William Champion patents a process for the production of metallic zinc by distillation from calamine and charcoal
- **1740:** Benjamin Huntsman developed the crucible steel technique
- **1799:** Alessandro Volta makes a copper/zinc acid battery

Nineteenth century

- **1824:** Patent issued to Joseph Aspin for portland cement
- **1825:** Hans Christian Orsted produces metallic aluminum
- **1839:** Charles Goodyear invents vulcanized rubber
- **1855:** Bessemer process for mass production of steel patented

Twentieth century

- **1903:** Precipitation hardening of Al, the first nanotechnology. This process is often referred to as age hardening. The Wright Bros used an alloy of Al + 8wt% Cu for the engine

in their plane. Fe engines were too heavy to get off the ground. Similar Al-Cu alloys have been used extensively in the aircraft industry ever since, for the main structure and skin of the aircraft. In the literature you will often see this discovery attributed to Alfred Wilm who published a paper on the subject in 1911 and received a patent.

- **1909:** Leo Baekeland presents Bakelite, a hard, thermosetting plastic
- **1911:** *Heike Kamerlingh Onnes* discovers superconductivity
- **1912:** *Harry Brearley* invents stainless steel
- **1931:** *Julius Nieuwland* develops the synthetic rubber called neoprene
- **1931:** *Wallace Carothers* develops nylon
- **1938:** *Roy Plunkett* discovers the process for making polytetrafluoroethylene, better known as teflon
- **1947:** First germanium transistor invented
- **1951:** Individual atoms seen for the first time, using the field ion microscope.
- **1953:** *Karl Ziegler* discovers metallic catalysts, allowing the production of polyethylene polymers with greatly improved strength.
- **1954:** Six percent efficiency silicon solar cells made at Bell Laboratories.
- **1968:** Liquid crystal display (LCD) developed by RCA
- **1970:** Silica optical fibers grown by Corning Incorporated
- **1980:** Development of duplex stainless steels that resist oxidation in chlorides.

Obviously the production and heat treatment of Fe-C alloys and Al-Cu alloys are among the greatest technological developments in human history.

Although the later topics in this text book will cover the details about all important materials. For a cumulative reference, here the origin and applications of few of them will be given.

0.3. SCOPE OF MATERIAL SCIENCE

The scope of any engineering discipline in a particular country depends on:

- The kind of industries which are operating in that country and
- The research related activities associated with it.

In India, there are many industries in the field of information technology so information technology or computer science graduates are currently in demand. Though material science is a base branch, material scientists are rarely required to run day to day industrial activities. Industries require mechanical or electrical engineers for maintaining and smooth running of their plants. So in general the demand of material scientists is lesser compared to other branches. Material scientists are more required for the product development research or towards R&D side.

While comparing with other countries, there are not many industries in India which require material science graduates. France, Germany being advanced countries with developed industrial infrastructure and R&D structure, will definitely have more scope for material science graduates. But on the other hand, Material Science, is a branch of engineering, where the sun will never set, an annual requirement of 5/6000 is seen in all various Industrial establishments. As the countries economy grows, a need arises to put in place infrastructures from factories to cars to planes to ports very rapidly the leader for all these, is products/equipments with good designs. Designs which requires good metallurgist to give products/materials which are durable, compact, eco friendly and are safe.

While we all admire a beautiful BMW, Mercedes, it is the effort of the material engineer, who have improved upon the designs by giving studier, lighter sheet metal and providing materials which imparts better finish to that BMW, Mercedes.

Various Designations which a Material Engineering Specialist occupy:

- Metallurgist
- Plant equipment engineer
- Quality planning engineer
- Supplier development engineer
- Welding engineer
- Ballistics engineer
- Senior process engineer

Whenever human beings need to build anything, the first question that comes to them is what should be the material that we have to use? Is it reliable and cheap? What can we do to improve the reliability? Do we need to change an entire process to improve reliability or can I change some structure in the material itself to improve reliability? What other materials I can use? What will happen to a material if there is a sudden change in the environment? Most of the Metallurgy and Materials Science engineers know the answers to these questions. The scope in this Material and Metallurgy broad field of study are as follows:

1. Composite Materials: These are the materials that use two or phases and provide a combined enhanced desired properties at

low strength to weight ratios. These materials are not only useful for mechanical but are equally important for civil construction/architecture designs and electrical devices.

2. Multifunctional Materials: Conventional materials like metals, ceramics and polymers are modified and designed such that they can change their properties with the change in environment. For e.g. shape memory alloys, Piezoelectric materials, superconductive materials.

3. Nanotechnology: In next 10–15 years we will move from “silicon age” to “nano age” where particles having size of nanometers range is developed. Nano materials have enhanced electronic properties, optoelectronic and physical properties. Quantum mechanics plays a very important role in providing the properties to materials. Nanotechnology field is not only studied by a material scientist but also by electronic engineers, Chemical engineers and Biotechnology engineers.

4. Extractive Metallurgy and Energy Engineering: The fuels required to extract to obtain metals are exhausting. Thus we are finding ways to obtain metals at higher efficiency with minimum energy consumption.

5. Physical Metallurgy: In this field of study, people are finding various ways to improve the properties of materials by controlling the microstructures of materials.

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|-----------------------|----------------------|
| 6. Nuclear materials | 7. Bio materials |
| 8. Coating techniques | 9. Powder metallurgy |
| 10. Thin films | 11. Metallic glasses |

From above we can conclude that scope of material science covers all the branches of engineering ranging from conventional disciplines like civil, electrical, electronics engineering to unconventional fields like nuclear, chemical, automobile, refrigeration etc.

0.4. OVERVIEW OF DIFFERENT ENGINEERING MATERIALS AND THEIR APPLICATIONS

Wood

Before stone there was wood. We humans are, after all, products of the forests. No material has followed the history of our species, from millions of years ago in the heart of Africa to the present than wood has. This is naturally occurring fibrous composite material used for the manufacture of *casting patterns*.

Ceramics

The use of ceramics—as fired clay—goes back to around 6000 BC, the late stone age, when they formed clay bowls and baked them in the campfires. The earliest of the great civilizations—in Mesopotamia (modern Iraq), China, and India—created practical containers and colourful tiles, statues, and jewellery. Combining clays with other minerals and then firing the mixture resulted in brilliant colors—the first glazes. Modern ceramic science evolved from the 1700's from the European development of porcelain. Chinese porcelain was first created in 600 AD. In the 1870's refractory materials able to withstand extremely high temperatures were developed using materials made from lime and magnesium oxide (or magnesia). In 1887, *Thomas Edison* directed the first advanced ceramic research. He directed the testing of a broad range of ceramic materials for resistivity for use in his latest invention, the carbon microphone.

These are produced by baking naturally occurring clays at high temperatures after moulding to shape. They are used for *high-voltage insulators and high-temperature-resistant cutting tool tips*.

Fiber and Cloth

One of the qualities of cloth that has appealed is its great variety. The Chinese discovered 5,000 years ago that they could use the fine exudations of the silkworm larva to make a thin and exquisite cloth. About the same time, cloth makers in India and Egypt were spinning the fibers of the cotton plant into a remarkably versatile fabric, one that they could weave into a range of weights and textures.

Brass

Cu-Zn alloy, corrosion resistant, used in costumes, jewellery, musical instruments and coins.

Bronze

We do not know how craftsmen came up with this combination, but thousands of years of working with copper preceded the discovery of bronze some 5,000 to 6,000 years ago (in a number of places). As the first intentionally produced alloy, bronze started the use of metals, mainly for weapons. Now a days used for bushings, landing gears.

Iron and Steel

Even in the 21st century, no more important metal exists than iron, and this has been true for as much as 3,000 years. Historically, there have been three basic forms of iron:

- Wrought iron,
- Cast iron, and
- Steel.

Craftsmen relying entirely on experience and observation discovered each of these forms and used them for centuries. In 19th century the constituent differences among them were understood, particularly the role of carbon. Historically, cast iron was the product of blast furnaces, first used by Chinese metalsmiths perhaps as early as 2,500 years ago.

They are the strongest materials available and are used for applications where high strength is required at relatively low cost and where weight is not of primary importance.

- As an example, ferrous metals are used for: bridge building, the structure of large buildings, railway lines, locomotives and rolling stock and the bodies and highly stressed engine parts of road vehicles.

Glass

The first glass was probably made by accident, as sand found its way into a kiln and then fused. This resulted in a material resembling a ceramic in cold brittleness but actually very different in structure and properties. Coloured glass beads, found in Eastern Mesopotamia and Egypt are believed to date back to around 3500 BC.

Two major breakthroughs took place. One was the art of glass blowing attributed to the Syrians between 27 BC and AD14. The other was the introduction of manganese oxide to create clear glass by the Romans who began using it for cast glass windows (with poor optical qualities) around AD100. Glass was much too expensive for common use in windows until about the 17th century. This is a hardwearing, abrasion-resistant material with excellent weathering properties.

It is used for electrical insulators, laboratory equipment, optical components in measuring instruments etc. and, in the form of fibers, is used to reinforce plastics. It is made by melting together the naturally occurring materials: silica (sand), limestone (calcium carbonate) and soda (sodium carbonate).

Paper

Paper is one of a number of inventions that came out of an astonishingly creative period in China about 2,000 years ago. When fibers—either directly from a plant or, more typically, from discarded cloth—are permitted to soak and partially rot, they can be reconstituted into randomly entangled sheets.

Plastics and Rubber

For thousands of years, our ancestors appreciated distinguished by their smooth and often colorful appearance: Ivory, tortoiseshell, and horn (forms of plastic) could be turned into small luxury items that had

an elegance hard to achieve in other substances. The first commercial plastic was celluloid, made from nitrated cotton and camphor. When this combination was heated under pressure, it transformed into a versatile substance Du Pont started the first research to find new macromolecules in 1929.

Closely related to these plastics was rubber, which started out as a natural product brought to Europe by explorers of South America. They used the milky sap of *Hevea brasiliensis* for waterproofing and making bouncing balls. The Europeans adapted lumps of dried sap to rub out pencil marks (hence the name “rubber”). In 1840 **Charles Goodyear** discovered how to make the material into a range of stable forms, good for combs to inflatable rafts. The rubber pneumatic tyres proved necessity for motor transport in the 20th century, and this dependence led to the invention of synthetic rubber.

This is used for hydraulic and compressed air hoses and oil seals. Naturally occurring latex is too soft for most engineering uses but it is used widely for vehicle tyres when it is compounded with carbon black.

Aluminium

Aluminium is the most abundant metallic element in the earth's crust. The salts of aluminium had been used by the Greeks and Romans for dying and as a wound dressing but it was not until 1808 that *Humphrey Davy* identified the metal base. *Wohler* is credited in 1827 as being the first to isolate aluminium as a metal.

In the 1880s, two young chemists, *Heroult in France* and *Hall* in the United States, independently at same time discovered how to make pure aluminium metal by an electrolytic process for the freeing of aluminium from its ore (aluminium oxide) using the addition of a new solvent fused cryolite Na_3AlF_6 . This “electrolytic process” made the metal readily available, depending only on the availability of cheap electricity. The *Hall-Heroult* process is still the only commercial process to produce aluminium.

They are used where their special properties such as corrosion resistance, electrical conductivity and thermal conductivity are required. Copper and aluminium are used as electrical conductors and, together with sheet zinc and sheet lead, are use as roofing materials. Structural, aircraft parts and packaging. They are also used alloyed with other metals to improve their strength.

Titanium Ti Alloys

Reactive only at high temperatures, is used for space and bio medical applications.

Magnesium Mg Alloys

Very low density and is finding applications in bio materials and spaceship materials.

The other most important material discoveries included cobalt (1730-1737), tungsten (1783), chromium (1798), nickel (1804) magnesium (1852) and titanium (1910).

0.5. IMPORTANCE OF MATERIALS

In engineering, successful design depends upon the selection of materials having the most desirable properties for a given function, whilst at the same time taking into consideration the cost of the materials and the problems connected with the bringing of these materials to the required shape. The engineer needs to know a great deal about the properties of a material before deciding on its use. The following simple examples will serve to illustrate the importance of the knowledge of the properties of the engineering materials.

Cast iron is the cheapest metal available to the engineer but its brittleness prevents its being worked other than by casting or machining. It is fairly good to work this metal by these processes.

Steel is almost twice as rigid as cast iron and as a result will not deflect so readily under the cutting forces encountered if its use is made for the beds of machine tools. However, because of the greater cost and difficulty of casting steel, cast iron is usually chosen for the purpose. This choice may also be affected by the way in which cast iron damps out vibrations in moving parts and the fact that two pieces of cast iron will run in contact without seizing.

The ductility of copper makes it ideal for drawing into tubes, but if this tubing is exposed to strong acids in service it will be corroded rapidly. Glass or plastic tubing would then be a better choice.

In case an ordinary steel is used instead of stainless steel in extremely corrosive situations, that indicates a wrong use of material and incompetency on the part of the engineer who design that article.

If an engineer plans to shape a cast iron part by forging, he will not be successful in that. On the other hand, it indicates his inadequate knowledge about the material and their properties.

Silver is the best conductor of electricity but its cost prohibits its use for carrying electric currents for a commercial use. Copper is almost as good a conductor and is far cheaper.

Thus, *we conclude* that to be successful in the use of material, it is essential for an engineer to have adequate knowledge about the various materials available to him and their properties.

0.6. CLASSIFICATION OF MATERIALS

Engineering materials are mainly classified as:

1. Metal

(a) Ferrous metals

(b) Non-ferrous metals.

2. Non metals.

1. Metals. Those materials which possess lustre (on polishing), strength and conductivity are generally known as metals or metallic materials *e.g.*, copper, iron, aluminium, nickel etc.

Metals in chemistry are defined classically as those elements which can replace one or more atoms of hydrogen from an acid. The basic criterion of the replacement of hydrogen atoms is the valency electron.

Metals and their alloys used in engineering industry and construction are broadly classed into:

(a) Ferrous metals

(b) Non-ferrous metals.

(a) *Ferrous Metals.* All metallic materials having iron (ferrum = iron) as their main constituent are popularly known as **ferrous metals or ferrous materials**, *e.g.*, wrought iron, steels, grey iron, etc.

(b) *Non-ferrous Metals.* Those metallic materials which do not possess iron as their main constituent are popularly known as **Non-ferrous metals** and (non-ferrous alloys), *e.g.*, copper, zinc, tin, lead, brass etc.

2. Non-metals. Those materials which mostly have low value of lustre, strength and conductivity are known as **non-metals or non-metallic materials**, *e.g.*, carbon, sulphur, phosphorus, glass, etc.

Note. Those elements which possess characteristics *i.e.*, properties of both metals and non-metals are known as **Metalloids**, *e.g.* antimony and arsenic.

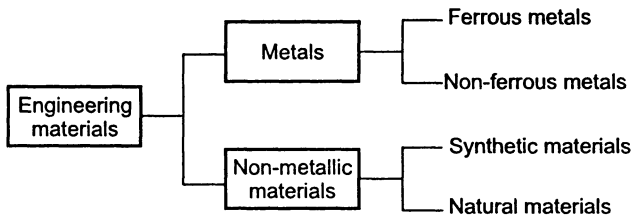


Fig. 0.1

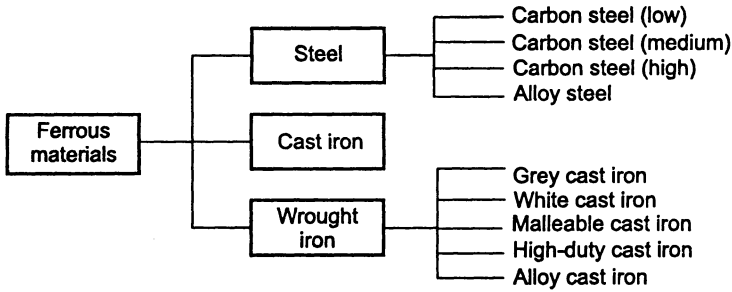


Fig. 0.2. Classification of ferrous metals.

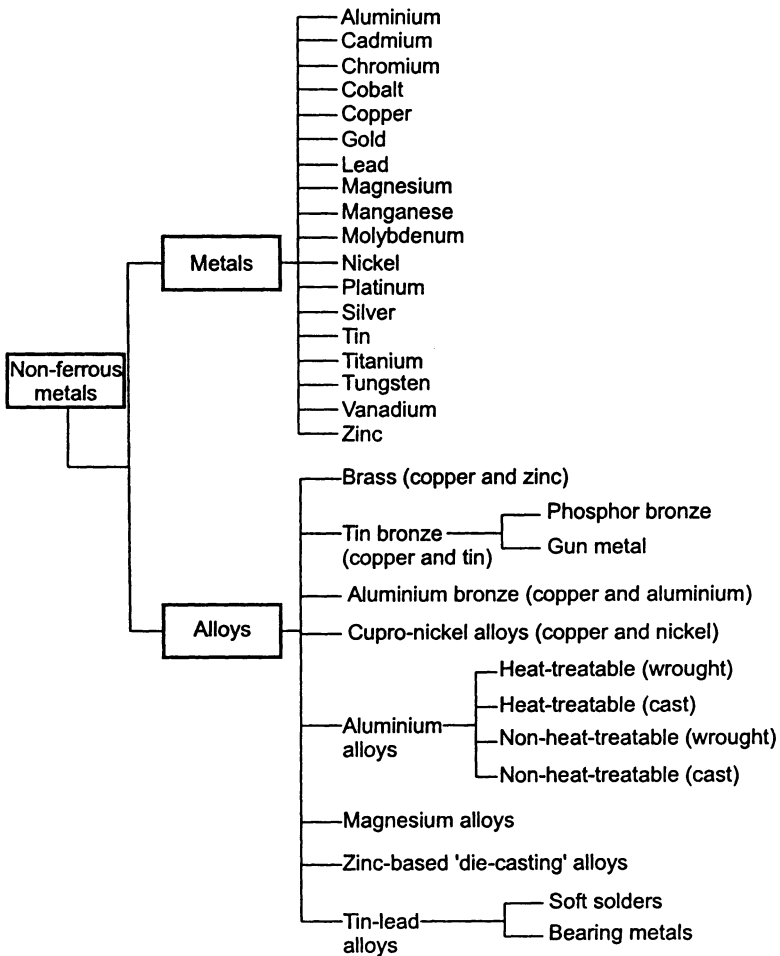


Fig. 0.3

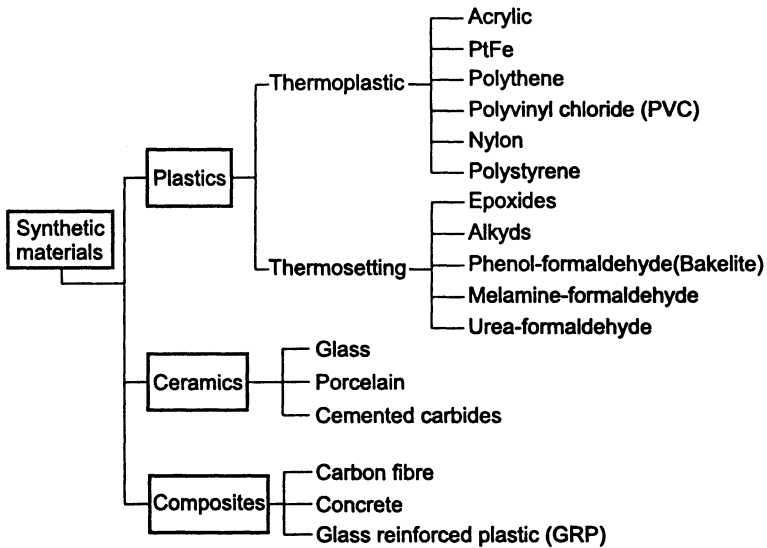


Fig. 0.4

0.7. DIFFERENCE BETWEEN METALS AND NON-METALS

The difference between metals and non-metals are not always sharply defined. The main points of difference between metals and non-metals are as given below:

TABLE 0.1

Sl. No.	Point / Property	Metals	Non-metals
1.	Lustre	They have lustre. When copper, lead etc. are freshly cut, they have a shining appearance.	They do not have metallic lustre.
2.	Physical State	Metals are normally solid at room temperature (with the exception of mercury).	They exist in all the three forms (i.e., solid, liquid and gaseous).
3.	Density	They generally possess higher density.	They generally possess lower density.
4.	Hardness	They are generally hard.	They vary in hardness from very soft to very hard.

5.	Malleability	They are generally malleable, <i>i.e.</i> they can be beaten into plates.	Solid non-metals are generally hard and brittle.
6.	Ductility	They are generally ductile, <i>i.e.</i> , they can be drawn into fine wires.	They do not possess this property.
7.	Strength	They are generally stronger than non-metals.	They are generally less strong than metals.
8.	Melting point	Most of them have high melting point.	Most of them have low melting point.
9.	Conductivity	They are generally good conductors of heat and electricity.	They are mostly bad conductors of heat and electricity.
10.	Nature of oxide	They form basic oxides with oxygen.	They form acidic oxides with oxygen.
11.	Nature of halogen compounds	Their halogen compounds are stable in water.	Their halogen compounds are generally decomposed by water.
12.	Electro-chemical nature	Metals are electro-positive elements. In an electrolysis, they form cations which are deposited on cathode.	Non-metals are either electronegative elements or show only very feeble electro-chemical properties. In an electrolysis, they form anions, which go to anode.
13.	Action with acids	They generally dissolve in acid and give off hydrogen.	They do not give off hydrogen with acids.
14.	Chemical bond	Metallic bond.	Ionic or covalent bond.

Exceptions

Certain properties commonly supposed to be characteristics of metals are subject to exceptions.

(i) **Lustre.** Not only metals have a metallic lustre but certain non-metals like iodine and graphite have also a metallic lustre.

(ii) **Melting Point.** There are certain metals like sodium and potassium which have low melting points. Sodium melts at 97°C and mercury is liquid at room temperature. Carbon, non-metal, does not melt even at the temperature of an electric arc.

(iii) **Density.** The alkali metals are lighter than water, *e.g.*, lithium has sp. gravity of 0.53. Iodine, non-metals, has a specific gravity of 4.9.

(iv) **Conductivity.** Not only metals are good conductors of heat and electricity, but certain non-metals such as graphite and gas carbon are also good conductor of electricity. Some metals, *e.g.* bismuth and lead, are relatively poor conductors of electricity.

(v) **Action with Acids.** All metals do not give off hydrogen by reaction with acids, for example copper, mercury, silver, gold platinum etc., do not displace hydrogen from acids.

(vi) **Electrochemical Nature.** In an electrolysis, not only metals are given off at the cathode, but certain non-metals like hydrogen are also given off at the cathode.

(vii) **Ductility and Malleability.** Certain metals, like bismuth, do not possess ductility and malleability, *i.e.* they are brittle. Plastic sulphur may be regarded as a malleable non-metal.

(viii) **Hardness.** All metals are not very hard, *e.g.*, lead is so soft that it can be easily stretched by a nail of a finger. Diamond (carbon) a non-metal, is the hardest substance so far known to the man.

0.8. PHYSICAL PROPERTIES

Physical properties are those that can be observed without changing the identity of the substance. The general properties of matter such as colour, density, hardness, are examples of physical properties.

Those properties of a material which are discussed in the field of physics are known as physical properties.

Physical properties are inherent in a material and they are determined by the electron structure and bond. For the most part they can be altered by changing the chemical composition (as in case of alloy).

In the case of metal, they include lustre, colour, dimension (size and shape), density, electric and thermal conductivity, bond, strength and melting point.

1. **Lustre.** The ability of the surface of a material to reflect light is known as lustre.

In other words, it is the property of brightness of the surface of a material.

All metals when polished have lustre (except lead). This property is absenting in non-metals with the exception of iodine and graphite.

The property of lustre is greatly helpful in classifying a material as metallic or non-metallic.

2. Colour. The property of a material of displaying (showing) a particular hue in the normal day-night is known as **colour**.

The colour of a material depends upon the wavelength of light which that material can absorb and also on the state (solid, liquid etc.) of the material. The presence of free conduction electrons in metals accounts for their characteristic lustre (*i.e.*, colour with lustre). The free electrons absorb the incident radiation and then retransmit it at the incident frequency. In some cases, there is absorption, as in the cases of copper and gold resulting in the transmission of radiation with frequency different from that of the incident radiation.

Many metals have specific colours which distinguish from other metals, *e.g.*, yellow colour of gold, reddish brown colour of copper in the ordinary form. Alloying elements change or modify the colour of a metal, *e.g.*, colour of copper can be changed to yellow by alloying it with zinc and tin.

The colour of a metal is a great help in its identification at room temperature in normal day-light.

3. Density. The weight per unit volume of a material is known as its density.

The ratio of the density of material to the density of water is known as **specific gravity** of that material.

The density is constant for a specific material, but different materials possess different density. Most of metals have higher density than of non-metals. The density of alloys is generally found to be intermediate between those of the alloying elements; but the relationship is seldom linear. An examination of the periodic table of elements shows that density increases regularly with increasing atomic numbers in each sub group. Phase changes involve a re-arrangement of atoms and are accompanied with changes in density.

The increasing use of light metals, aluminium and magnesium shows the importance of density in engineering design and construction.

Sometimes it is advantageous to differentiate two pieces of different metals of the similar colour and lustre by comparing their densities.

4. Melting point. The temperature at which a solid material changes to liquid form is known as **melting point**.

In other words, it is the point (temperature) at which the solid phase is in equilibrium with liquid phase of the material and is expressed in *degree Kelvin* or *centigrade*. Some materials may not have sharp melting point.

The melting points of metals follow the periodic grouping. The metals with similar melting points fall into a group.

A metal possesses a specific value of its melting point under a given set of conditions. Pure metals have a sharp melting point, that is they change from entirely solid to entirely liquid form in a very small temperature range. Alloys normally have a much wider temperature interval.

Low melting metals and alloys have special applications in safety devices like safety plugs in boilers and fire extinguishers. In most cases they are eutectic mixtures.

Metals with high melting points are usually those which possess greater strength at high temperature. Alloys of iron, nickel and cobalt with molybdenum, tungsten, vanadium and chromium withstand high temperatures.

Table 0.2 indicates physical properties of some pure metals.

0.9. THERMAL PROPERTIES

Sometimes selection of materials are required for components that are exposed to elevated/below temperatures. Hence, temperature changes, and/or thermal gradients require the design engineer to have an understanding of the thermal responses of materials, as well as thermal properties of a wide variety of materials.

Those characteristics of materials which we come to know through thermal changes in the materials are known as their thermal properties. By the 'thermal changes' we mean addition or subtraction of heat, the raising or lowering of temperature.

We are concerned with the thermal behaviour of solids, which is important in such applications as thermodynamics, heat transfer, melting, thermal stresses and thermal shock.

The important thermal properties of solids are:

- | | |
|--------------------------|-----------------------|
| (i) Thermal conductivity | (ii) Specific heat |
| (iii) Thermal expansion | (iv) Melting point |
| (v) Thermal diffusivity | (vi) Spalling |
| (vii) Thermal fatigue | (viii) Thermal shock. |

1. Thermal Conductivity. It is the index of easiness with which heat is conducted by a given material.

The **co-efficient of thermal conductivity or the specific thermal conductivity (K)** of a substance is the number of joules of heat which flow in one second *i.e.*, as watts of heat, across 1 m^2 area of a slab of the substance of one metre thickness when the temperatures of the faces of the slab differ by one kelvin (or $^{\circ}\text{C}$). It is expressed in the units $\text{W}/(\text{m-K})$.

Table 0.2: Important Physical Properties of Some Pure Metals

<i>Metal</i>	<i>Symbol</i>	<i>Colour</i>	<i>Melting point °C</i>	<i>Density × 10³ kg/m³</i>	<i>Sp. Heat Cal/gm /°C</i>	<i>Co-efficient of linear expansion × (10⁻⁶) (K⁻¹) at 20°C</i>	<i>Thermal conductivity W/m-k</i>	<i>Electrical resistivity × 10⁻⁸ Ω-m</i>
Aluminium	Al	white with bluish tinge	660	2.699	0.215	23.0	235	2.69
Copper	Cu	yellowish red	1083	8.96	0.092	16.7	395	1.55
Iron	Fe	greyish	1535	7.87	0.109	11.7	73	9.71
Lead	Pb	bluish grey	327	11.34	0.031	29.1	33.5	20.60
Magnesium	Mg	silver white	650	1.74	0.245	26.0	159	4.4
Nickel	Ni	silvery white with yellowish cast	1453	8.90	0.105	12.8	63	6.84
Silver	Ag	white	961	10.49	0.056	18.9	419	1.6
Tin	Sn	silvery white lustrous with bluish tinge	232	7.298	0.054	21.4	67	12.8
Zinc	Zn	bluish white	419	7.133	0.092	33.0	108	5.9

Heat is transmitted through solids by two distinct mechanisms:

- By elastic vibrations of atoms and molecules, and
- By transfer of energy by free electrons.

The former occurs in all materials, but the latter is much more effective process when it can be utilized. The latter accounts for the high conductivity of metals which have a plentiful supply of free electrons. Because insulators must rely on the vibrations of atoms and molecules they have lower conductivities.

Electronic thermal conductivity (*i.e.*, by latter method) is almost independent of temperature. The conductivity of non-metallic crystals varies inversely with temperature. In amorphous materials like glass, thermal conductivity increases slightly with rising temperature.

Conductivity in crystals is different in different directions because of an isotropy of crystal structures. In polycrystalline and amorphous materials, however, conductivity is substantially isotropic.

When we wish an efficient transmission of heat through a material then we select a material with high thermal conductivity and vice versa. For example, we use copper for boiler tubes, heating coils and soldering iron bits because of its high thermal conductivity.

The Table 0.3 gives specific thermal conductivities of some materials in W/(m-K).

TABLE 0.3

1. Metals		2. Gases	
Aluminium	235	Air	0.0241
Brass (red)	160	Hydrogen	0.1397
Copper	395	Oxygen	0.0024
Silver	419	3. Others	
Steel	47	Asbestos	0.0846
Nickel	89	Concrete	0.8465
Tungsten	178	Cork	0.1693
		Glass	0.8465
		Wood	0.0846
		Ice	1.6929

Usually materials with high Debye temperature have high thermal conductivity.

Deybe temperature (θ_D) is a characteristic temperature of the material. It is given by the relation:

$$\theta_D = h V_m / k,$$

where, h = Planck's constant

k = Boltzmann's constant

V_m = the maximum frequency of thermal vibration of the lattice of the material.

2. Specific Heat. It is the quantity of heat in joules that must be added to one kg. of a material to raise its temperature through 1°K (or $^\circ\text{C}$). It is also known as specific heat capacity.

When heat is added to a solid, it increases the energy content; a certain part of energy goes into thermal vibrations (kinetic energy) and appears as a rise in temperature; the remainder goes into thermal expansion (potential energy) unless some structural change—crystal transformation, vaporization or melting or a chemical change occurs.

If we assume that no structural or chemical changes are involved, the specific heat capacity of a solid is defined by

$$C = \frac{1}{m} \cdot \frac{dE}{dT}$$

where, m = mass, E = total energy content, and T = temperature of the material. If m is taken as one unit of mass and increment in temperature as one degree, it reduces to more common definition.

$$C = \Delta E$$

The specific heat capacity of a substance varies with the conditions under which it is measured. If the substance is allowed to expand as heat is added, the work done against atmospheric pressure will divert some of the heat energy from the process of raising the temperature. Under these conditions the specific heat will be higher than if the volume is held constant.

It is conventional to use C_p for specific heat at constant pressure when volume expansion is permitted and C_v for the specific heat at constant volume when pressure increases enough to keep the volume constant. In solids and liquids the difference between C_p and C_v is so small as to be negligible except at very high temperatures. But for gas this difference is significant even at ordinary temperature.

Specific heat of solids increases slightly with increase in temperature and varies from metal to metal.

3. Thermal Expansion. It is increase in dimensions of a material on application of heat.

Practically all solids expand on heating and contract on cooling. Thermal expansion increases as the temperature of the solid rises. With the rise in temperature the vibrations in the lattice increase

and thus atomic and molecules move farther away from their average positions. The thermal expansion depends upon the interatomic and inter-molecular forces as well as on structural arrangement.

The **co-efficient of thermal expansion** (α or α_l) may be defined as the rate of change of length with respect to temperature, per unit length.

$$\alpha = \frac{1}{l} \cdot \frac{dl}{dT} \quad \text{since } dl/l = \epsilon, \text{ where } \epsilon \text{ is the strain,}$$

$$\therefore \alpha = \frac{d\epsilon}{dT}$$

Covalent and ionic crystals have much lower value of α than for metallic crystals.

Molecular solids have high thermal expansions. There are exceptions to this rule, *e.g.*, in some polymers the entropy of the system plays a dominant part and may result in a negative co-efficient of expansion.

Owing to their natural an isotropy crystals tend to have different thermal expansion in different directions. This is not true of cubic crystals, however, they are isotropic in this respect.

The expansion of a solid in its linear dimensions causes an increase in volume as well. The volume co-efficient of thermal expansion is denoted by α_v and it can be shown that for an isotropic solid,

$$\alpha_v = 3\alpha$$

Then, α is sometimes called the co-efficient of linear expansion to distinguish it from α_v .

The thermal expansion give rise to internal stresses if expansion is hindered in any way.

Thermal expansion is important in many practical situations. For certain types of precise equipment, dimensional changes due to temperature variations must be minimized, and some Fe-Ni and Fe-Co alloys that have low coefficients of thermal expansions ($\alpha_l = 1 \times 10^{-6} \text{ K}^{-1}$) over a limited temperature range may be used to advantage.

4. Melting Point. (It has already been discussed in Art. 0.6).

5. Thermal Diffusivity. It is the ratio of thermal conductivity of a material to its heat capacity per unit volume. Mathematically,

$$h \text{ (thermal diffusivity)} = \frac{K_t}{\rho C}$$

where, K_t = thermal conductivity, ρ = density

C = specific heat capacity.

Thermal diffusivity is the rate at which a disturbance in temperature of one part of a body travels to another part. It is also a measure of how little the disturbance is attenuated as it travels from point to point.

A high diffusivity is desirable in that it tries to reduce the thermal gradients caused by local heating thereby reducing the local stresses. Obviously a low K_t , by itself, does not necessarily mean a low diffusivity. Light weight insulating materials may have diffusivities as high as more dense materials. Metals, with their high conductivities always have high diffusivities. Since K_t varies with temperature, diffusivity does likewise. In dealing with problems of heat transfer, this fact should be kept in mind.

6. Spalling. It is cracking of brittle materials caused by thermal stresses in the surface layer. This characteristic is related to thermal expansion of solids.

When a brittle body is heated, compressive failures on 45° shearing planes cause splitting off of corners and edges and flaking of the surface. Cooling causes tensile cracks at right angles to the surface. Resistance to spalling is indicated by the thermal shock parameter. Spalling is of importance in ceramic materials.

7. Thermal Fatigue. It is mechanical effects of repeated thermal stresses on a solid caused by repeated heating and cooling of the solid.

Since thermal stresses can be very large, involving considerable plastic flow, fatigue failures can take place after relatively few cycles (*i.e.*, low cycle fatigue failure). The effect of the high part of the temperature cycle on the strength of the material is also an important factor in reducing the life of the materials under thermal fatigue.

8. Thermal Shock. It is impulse effect produced within a solid due to a sudden change of temperature.

On the other hand, 'thermal shock resistance' is the ability of a material to withstand thermal stresses due to sudden and severe changes in temperature.

Thermal diffusivity is an important factor here too, because if heat can be dissipated rapidly enough, the effects of the shocks are considerably reduced. Other controlling factors of thermal shocks are the coefficient of thermal expansion, α , the modulus of elasticity, E , the mechanical strength, fu , and Poisson's ratio, μ . A thermal shock parameter is a variable which combines the effect of all the factors to indicate the capacity of a given material to absorb thermal shocks. The most widely accepted parameter is as follows:

$$P = \frac{fu}{E\alpha} \sqrt{\frac{K_t}{\rho C}}$$

The quantity $\frac{f_u}{E\alpha}$ seems to be most important factor in shock

resistance. A material having low strength can still have a high P if E is low enough, as in plastics.

0.10. CHEMICAL PROPERTIES

Properties that describe how a substance changes into a completely different substance are called chemical properties. These normally describe what chemical reactions are likely to occur.

Flammability and corrosion/oxidation resistance are examples of chemical properties. We can observe how a sample reacts when mixed with other chemicals (water, acid).

0.10.1. Flammability

A material that can burn is described as flammable. Some materials rust (a type of oxidation reaction). Some materials dissolve in water or other liquids.

Usually a chemical reaction involves a transformation of the sample into a different substance, and it may be difficult to reverse the process. For example, wood is flammable.

When it burns it combines with oxygen from the air. The reaction produces ashes, smoke and water; it cannot be reversed to make wood. The products of the reaction have quite different properties from the original wood.

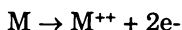
0.10.2. Corrosion

Corrosion involves the deterioration of a material as it reacts with its environment. Corrosion is the primary means by which metals deteriorate. Corrosion literally consumes the material reducing load carrying capability and causing stress concentrations. The corrosion process is usually electrochemical in nature.

Corrosion is a natural process that commonly occurs because unstable materials, such as refined metals want to return to a more stable compound. For example, some metals, such as gold and silver, can be found in the earth in their natural, metallic state hence, they have little tendency to corrode. Iron is a moderately active metal and corrodes readily in the presence of water. The natural state of iron is iron oxide and the most common iron ore is Hematite with a chemical composition of Fe_2O_3 . Rust, the most common corrosion product of iron, also has a chemical composition of Fe_2O_3 .

Corrosion involve two chemical processes...**oxidation** and **reduction**. *Oxidation is the process of stripping electrons from an atom and reduction occurs when an electron is added to an atom.* The oxidation process takes place at an area known as the anode. At the anode, positively charged atoms leave the solid surface and enter into an electrolyte as ions. The ions leave their corresponding negative charge in the form of electrons in the metal which travel to the location of the cathode through a conductive path. At the cathode, the corresponding reduction reaction takes place and consumes the free electrons. From this description, it can be seen that there are four essential components that are needed for a corrosion reaction to proceed. These components are an anode, a cathode, an electrolyte with oxidizing species, and some direct electrical connection between the anode and cathode. Although atmospheric air is the most common environmental electrolyte alongwith natural waters, such as seawater rain.

Corrosion will proceed at the anodic site according to a reaction such as



where M is a metal atom. The resulting metal cations (M^{++}) are available at the metal surface to become corrosion products such as oxides, hydroxides, etc.

The liberated electrons travel through the bulk metal (or another low resistance electrical connection) to the cathode, where they are consumed by cathodic reactions such as $2H^{+} + 2e^{-} \rightarrow H_2$

0.10.2.1. Types of Corrosion

The various types of corrosion can be broadly classified as:

(i) Contact corrosion (ii) Micro corrosion (iii) Concentration corrosion (iv) Stress corrosion (v) Grain boundary corrosion.

(i) **Contact Corrosion.** It is caused by the metallic contact of two or more metals possessing different electro-chemical potentials. This type of corrosion can be remedied by introducing an electric insulation or preventing the penetration of electrolyte by greasing such surfaces, etc.

(ii) **Micro Corrosion.** It is caused because of an alloy containing several phases, with different electrochemical potentials with respect to each other. An application of protecting surface layer or choice of another alloy helps in preventing this type of corrosion.

(iii) **Concentration Corrosion.** It is caused when a metal is surrounded by an electrolyte of non-uniform concentration. It can be prevented by coating the metal with a protective layer or making the electrolyte more uniform.

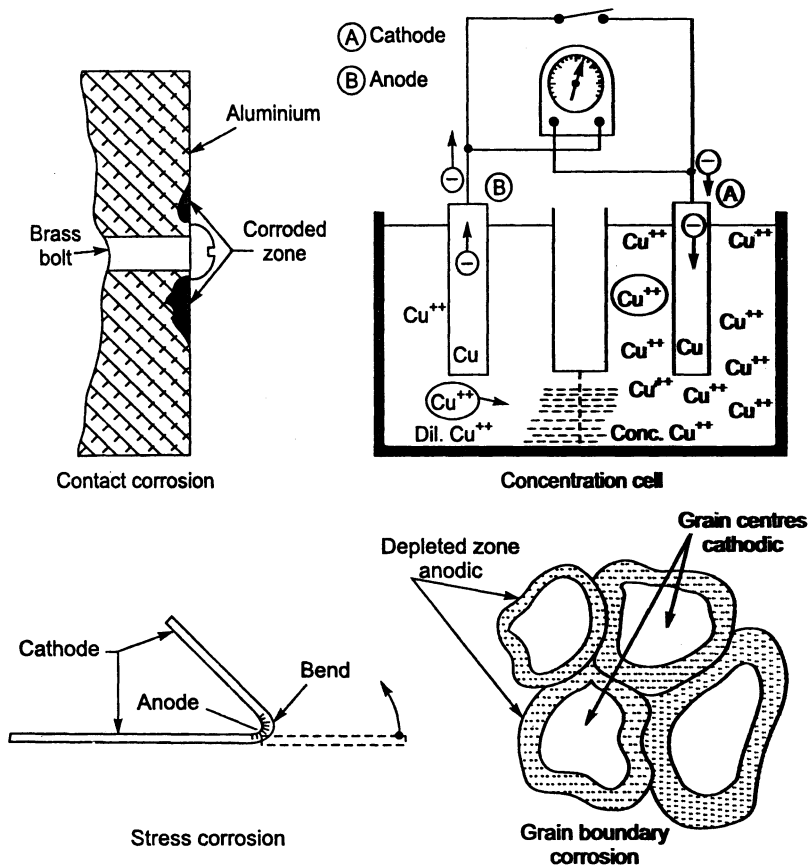


Fig. 0.5. Illustrates some types of corrosion.

(iv) **Stress Corrosion.** Mechanical stresses are different at different points. Under such circumstances, especially tensile stresses produce cracks etc. in the surface layer to cause corrosion. It can be remedied by providing a protective coating on the metal or heating it to relieve it of stresses.

(v) **Grain Boundary Corrosion.** It is caused in an alloy by the precipitation products at the grain boundaries which cause different electrochemical potentials. It can be prevented by causing precipitation products to dissolve by means of heat treatment.

0.10.2.2. Corrosion Prevention and Control

Any one or more of the means given below can be adopted to prevent corrosion depending upon the service conditions.

These measures of combating corrosion can be listed as below:

1. Internal Measures

(i) **Purification of metals.** Pure metals have better corrosion resistance than impure metals.

(ii) **Alloying of metals** with corrosion resistant elements.

(iii) **Proper heat-treatment of metals.** Proper heat-treatment given to a metallic piece also helps to control its corrosion. For example, annealing is often necessary to remove internal stresses of cold worked parts and thus avoid their stress-corrosion.

2. External Measures

- **Design features.** Life of equipment can be prolonged by reducing its corrosion by careful designing, such as avoiding side by side contact of dissimilar metals or to avoid impingement and turbulence in flowing environment or to avoid crevices etc.
- **Application of inhibitors.** Inhibitor may be defined as any substance which when added in a small quantity to the environment reduces the corrosion rate appreciably.
- **Alteration of corrosive environment.** Often it is helpful to control corrosion by suitable alteration of the nature, composition and temperature of environment or removal of dissolved gases.
- **Protective coatings**
 - (a) *Metallic coatings.* These may be provided of zinc, tin, aluminium, nickel etc. by either of the methods like electroplating, dipping in molten metal, cladding, metal spraying, cementation or vapour deposition.
 - (b) *Non-metallic coatings.* The various such protective coatings consist of painting, lacquering, plastic coating, vitreous enamelling, slushing compound coatings, anodising and other oxide films and chemical dip coatings.
- **Cathodic protection.** If a surface of steel or other metal requiring protection is made cathode, current will flow through an electrolyte only to it and not from it. It will be subjected to a reducing, not an oxidising effect. Local galvanic cells on its surface will be obliterated by a higher external potential. For these reasons it will not/corrode. The external potential may be obtained from an electrical source.

0.11. ELECTRICAL PROPERTIES

Those characteristics of a material which are revealed only when an electric current is passed or is tried to pass through it, are known as

electrical properties. These are conductivity, resistivity superconductivity and dielectric property.

1. Electrical Conductivity. The property of a material by virtue of which it allows the flow of electric current is known as **conductance**.

The conductance between the opposite faces of a portion of a material having unit cross-sectional area and unit length is known as **electrical conductivity**. It is reciprocal of electrical resistivity. It is expressed in mho/cm.

It is the ease to the movement of electrical charge from one position to another. The charge may be carried by **ions** or **by electrons**. The electrical conductivity varies from material to material.

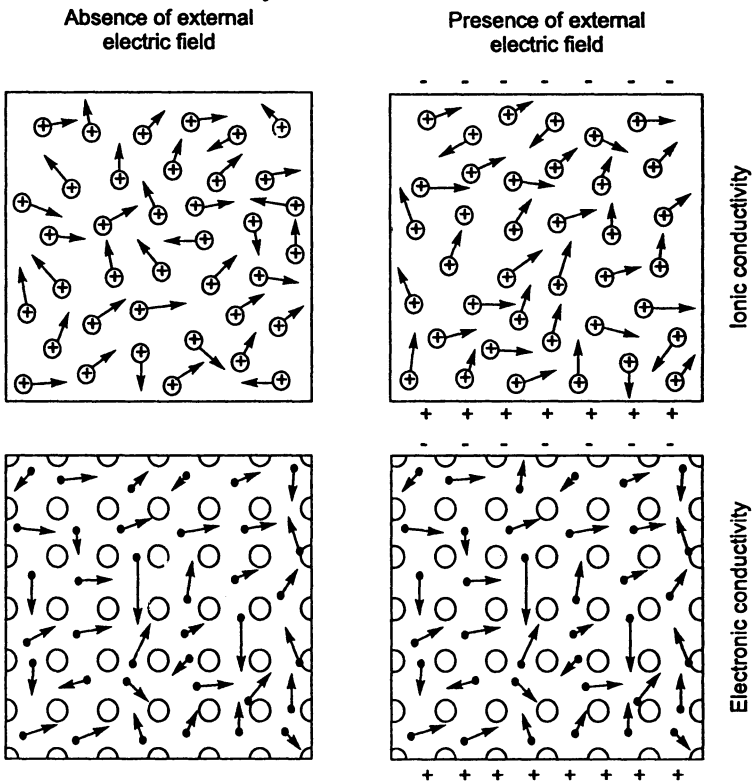


Fig. 0.6. Electric conductivity.

In ionic conductivity, the carriers of electrical charge may be either negative or positive ions. In **electronic conductivity**, the carriers of electrical charge are electrons or electron "holes". The charge per electron is 1.6×10^{-19} coulomb (*i.e.* ampere-second). Ions contain either a deficiency or an excess of electrons. The charge per ion is an integral multiple of 1.6×10^{-19} .

Conductivity may be expressed as a product of:

- The number of charge carriers in a material,
- The charge carried by each carrier, and
- The mobility of the carriers.

Ionic conductivity increases with temperature because the mobility of the ions is increased with temperature. But in a field of the same strength, ionic conductivity is much lower than electronic conductivity. The reason being, a given voltage gradient cannot accelerate the comparatively large ions as it can to the small electrons.

Due to the mobility of their valence electrons, metallic solids are generally good conductors of electricity. The electrons in materials pass through the lattice unscattered without encountering any resistance when there are no lattice vibrations or defects and metal lattice are perfect. The scattering of the electrons is generally caused by the presence of lattice defects and impurity atoms as well as the thermal vibration of lattice atoms. This scattering of the electrons is responsible for electric resistance of the materials.

The Table 0.4 below shows electrical conductivity of metals as a percentage with silver as 100% conductivity.

TABLE 0.4

1.	Silver	100.0	2.	Copper	94.0
3.	Gold	66.0	4.	Aluminium	53.0
5.	Magnesium	35.5	6.	Molybdenum	32.2
7.	Tungsten	28.9	8.	Zinc	26.0
9.	Cadmium	21.2	10.	Iron	17.7

The electrical conductivity of silver $6.3 \times 10^7 \Omega^{-1} \text{ m}^{-1}$.

2. Resistivity. The property of a material by virtue of which it resists the flow of electric current is known as **resistance**.

The resistance offered to the flow of a current by unit cross-section of a material for its unit length is known as its **resistivity**.

Resistance R of a wire of constant cross-section is proportional to its length and inversely proportional to its cross-sectional area.

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

where, R = resistance in ohms (Ω),

l = length in metres,

A = cross-sectional area in m^2 ,

and ρ = resistivity in $\Omega\text{-m}$.

Resistivity is reciprocal of conductivity.

3. Superconductivity. It is the phenomenon of abrupt drop of resistivity of some materials, at a temperature called superconducting transition temperature before absolute zero is reached.

It is because of conduction by the drift of electrons in the direction of the applied electric field being opposed by irregularities within the lattice.

Superconductivity state can be destroyed by the application of a sufficiently strong magnetic field, either external or produced by current flowing through the conductor.

4. Semi-conductivity. It is the property of some non-metallic materials by virtue of which their electron structure allows for more valence electrons to be available by thermal energy than in the majority of insulators.

It is characteristic of material originating from structural imperfections or due to introduction of minute quantities of chemical impurities into the crystals.

5. Dielectric Characteristics. A dielectric is the material separating two charged bodies. For a substance to be a good dielectric, it must be an insulator; hence any insulator is called a dielectric.

The property of a system of conductors and dielectrics which permits the storage of electricity when potential difference is existing between the conductors is known as capacitance. Capacitance is expressed as a ratio of quantity of electricity to potential difference. Its unit is named as **farad**, which is the capacitance whose potential will be raised by one volt by the addition of a charge of one coulomb.

The ratio of the capacitance of a capacitor having a certain material as dielectric to the capacitance of that capacitor with vacuum (or air) dielectric is termed as **relative permittivity**, of that material and is represented by the symbol ϵ_r . The values of the relative permittivity of some of the most important insulating materials are given in the following Table 0.5.

TABLE 0.5

<i>Material</i>	<i>Relative permittivity</i>
Porcelain	6-7
Glass	5-10
Bakelite	4.5-5.5
Mica	3-7
Rubber	2-3.5
Paper (dry)	2-2.5
Air	1.0006

The potential gradient necessary to cause breakdown of an insulating medium is termed its **dielectric strength** and is usually expressed in kilovolts/millimetre. The value of dielectric strength of a given material decreases with increase of thickness, and the following Table 0.6 gives the approximate dielectric strengths of some of the most important materials.

TABLE 0.6

<i>Material</i>	<i>Thickness</i>	<i>Dielectric Strength (kV/mm)</i>
Mica	0.01	200.00
	0.10	115.00
	1.00	61.00
Glass	1.00	28.50
	5.00	18.30
Ebonite	1.00	50.00
Paraffin-waxed laper	0.10	40–60
Air (at normal pressure and temperature)	0.20	5.75
	0.60	4.92
	1.00	4.36
	6.00	3.27
	10.00	2.98

0.12. MECHANICAL PROPERTIES

Those properties of a material that define its behaviour under applied forces (*i.e.* load) are termed as mechanical properties.

These properties are expressed in terms of quantities that are function of stress or strain or both.

Before going into detail of various mechanical properties, certain fundamental terms connected with mechanical properties are being explained below:

Stress. It is defined as intensity of the internal distributed forces or components of forces resisting a change in form of a body under a load.

It is measured as the force per unit area. It is generally expressed in newtons per square millimetre of cross-sectional area. There are three basic types of stress namely, tensile, compressive and shearing stresses.

Strain. It is deformation or change produced in the dimension(s) of a material under the action of load. It is a ratio of the change in dimension to the original dimension of the material. It has no unit. There are three basic types of strains corresponding to the types of stresses namely tensile, compressive and shearing strains.

Strains are also known to be of two categories—elastic strain and plastic strain (or set or permanent set).

Elastic strain. It is a reversible change in dimension of a body when load is applied to it. It disappears after the removal of load. It changes proportional to the load. In this strain after the removal of load, same atomic neighbours are retained without any displacement.

Plastic Strain or Set or Permanent Set. It is the deformation or change in dimension of a body which remains in it after the removal of load. In other words, It is the strain permanently given to a material by applied stress. It is the strain of permanent displacement of the atoms inside the material.

The important mechanical properties are as follows: (Fig. 0.7 illustrates some mechanical properties.)

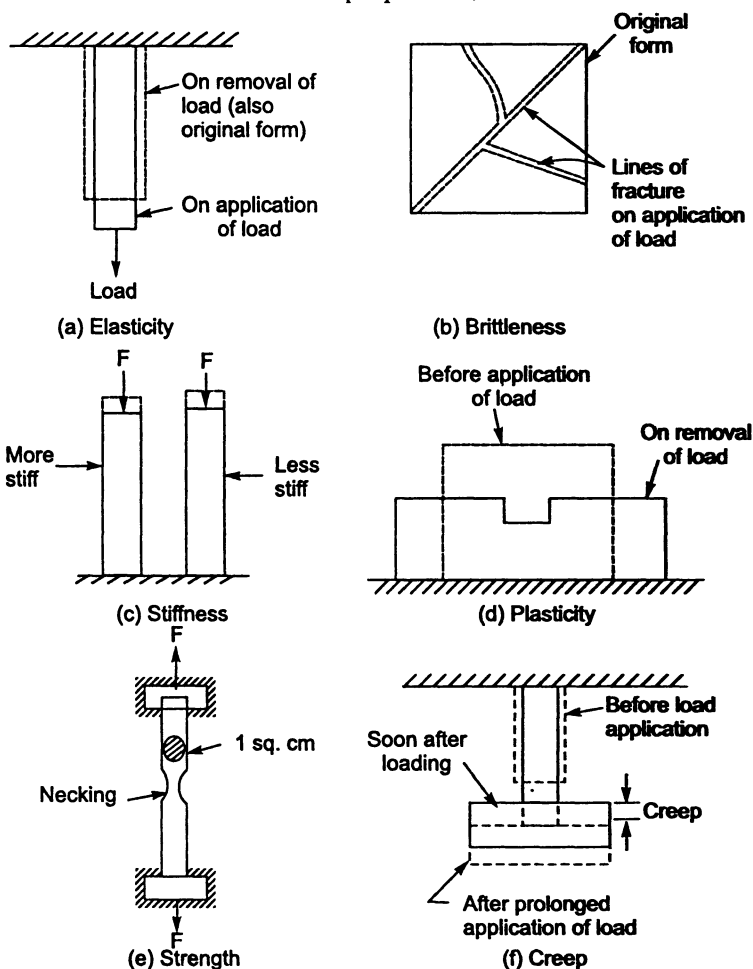


Fig. 0.7. (Contd.)

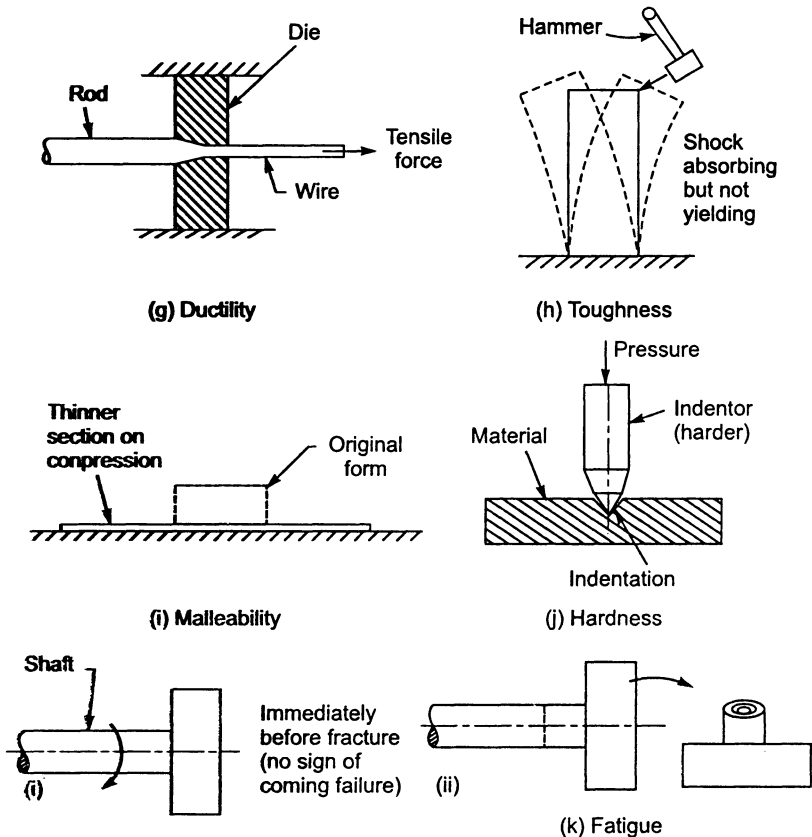


Fig. 0.7. Mechanical Properties.

1. Elasticity. The ability of a material to regain its original shape and size after the removal of load is known as *elasticity*.

A perfectly elastic body is considered to be one that completely recovers its original shape and dimension on removal of load. No materials are known which are perfectly elastic through out the entire range of stress upto rupture. Of course, some materials such as steel, appear to be elastic over a considerable range of stress. A practical index of elasticity in the elastic limit (stress) of the materials. Elastic limit of a material is the greatest unit stress that it is capable of facing without permanent deformation.

A material with high value of its elastic limit is considered to be more elastic than the material whose elastic limit is having lower value. That is why, steel is considered to be more elastic than rubber.

Good elasticity is desirable in materials used for components or members of machines and structures.

2. **Plasticity.** That property of a material by virtue of which it retains the shape given to it under the action of a force, even after the removal of the force, is known as **plasticity**.

Plasticity is quite opposite to elasticity. All metals possess plasticity to little or more extent. Most of the metals show more plasticity when hot than when cold. Lead shows sufficient plasticity at the room temperature. But, cast iron does not possess sufficient plasticity for any forging operation even when hot.

This property is of importance in forming, shaping and extruding operations on metals. Some metals are shaped cold, *e.g.*, deep drawing of thin sheets. But most metals are rendered plastic by heating and hence shaped hot, *e.g.*, the rolling of structural steel sections and forming machine parts.

3. **Strength.** The capacity of a material to withstand or support a load is called its **strength**.

Strength is generally expressed as newtons per square millimetre of the cross-section of the material. In use, a material may have to withstand a tensile, compressive or shear force. Hence the strength is according to the nature of load, *i.e.*, tensile strength, compressive strength or shear strength.

These days, strength of a material is determined with the help of a Universal Testing Machine.

The load necessary to fracture unit cross-section of a material is known as its **ultimate strength**. The ultimate strength of a material in tension is called its **tenacity**.

In general, when unspecified, strength means tensile strength of the material.

The strength may also be classified as

- (i) Elastic strength and (ii) Plastic strength.

Elastic Strength. That value of the strength of a material which corresponds the transition from elastic range to plastic range (*i.e.*, the stage where material shifts over from elastic to plastic behaviour), is known as its **elastic strength**. For defining elastic strength certain stress values are referred to in engineering practice. These stresses are known as **ideal stresses** because this cannot be measured very accurately. The limit of proportionality and elastic limit are such stresses.

Plastic Strength. That value of strength which corresponds to the plastic range and rupture of a material, is known as its **plastic strength**. Ultimate strength is the most popular of these plastic range stress values.

In practice, the greatest value of stress to which a material is subjected to, as a machine part or a part of structure, is known as

working stress. The value of this stress is to be kept below the elastic limit of the material. The ratio of ultimate strength of a material to its working stress is called **factor of safety**.

$$\therefore \text{Factor of safety} = \frac{\text{Ultimate strength}}{\text{Working stress}}$$

The elastic limit (or proof stress) is in reality a much more useful value than ultimate tensile strength in engineering design. Once elastic limit has been exceeded during loading, the metal has already begun to fail. Thus it has become more frequent practice to define factor of safety in terms of elastic limit or proof stress. Therefore, it becomes necessary to specify whether factor of safety is based on ultimate strength or proof stress.

$$\therefore \text{Proof factor of safety} = \frac{\text{Elastic limit or proof stress}}{\text{Safe working stress}}$$

The value of factor of safety selected for a particular component, greatly depends upon the condition of loading to which its material will be subjected to.

The strength of a material plays a vital role in deciding the different sizes of a component of a machine or a member of a structure.

4. Ductility. The ability of a material to be drawn from a large section to a small section is known as its **ductility**.

It is also defined as the property of a material enabling it to be drawn into wire with the application of a tensile force.

A ductile material must be both strong and plastic, *e.g.*, lead wire is difficult to draw because the strength of lead is low.

The usual measures of ductility are the percentage elongation and percentage reduction of area of a material in the tensile test on a universal testing machine or tensile testing machine.

Percentage Elongation. The percentage increase in the original length of a rod of a material under tensile load up to its fracture, is known as percentage elongation of the material.

$$\therefore \text{Percentage elongation} = \frac{\text{Max. change in length}}{\text{Original length}} \times 100$$

A good value of percentage elongation indicates a ductile material. Metals with more than 15% elongation are considered as ductile metals, while those with 5 to 15% elongation are of intermediate ductility. But metals with less than 5% elongation are called as brittle metals.

Percentage Reduction of Area. The percentage decrease in the cross-sectional area of a bar of a material when pulled axially in a testing machine upto its fracture, is known **percentage reduction of area** of the material.

$$\therefore \text{Percentage reduction of area} = \frac{\text{Decrease of X - Area}}{\text{Originally X - Area}} \times 100$$

A material with high values of percentage elongation and percentage reduction of area is, no doubt, ductile material. At the same time, a material with more percentage reduction of area can be drawn into thinner wire than the material whose percentage reduction of area has a lesser value, while both the materials may be having almost equal percentage elongation.

The commonly known metals in the decreasing order of their ductility are:

- | | | | |
|-----------|--------------|-----------|---------|
| 1. Gold | 2. Platinum | 3. Silver | 4. Iron |
| 5. Copper | 6. Aluminium | 7. Nickel | 8. Zinc |
| 9. Tin | 10. Lead. | | |

As discussed above, the ductility of a material is a useful property for drawing it into wires. This property is helpful in showing sufficient deformation in a machine component before its fracture in case of its overloading (in tension) and thus giving a warning before its failure.

5. Brittleness. The property of fracturing of a material without perceptible warning or without appreciable deformation is known as **brittleness**.

The brittle behaviour of a material may be due to brittleness of grain boundaries or that of crystals themselves. Brittleness is opposite to ductility. All non-ductile materials are said to be brittle. Concrete and cast iron are examples of brittle engineering materials.

Brittleness is sometimes also known as **shortness** in the case of metals. **Hot or red shortness** means that the metal is brittle when in red hot state. **Cold-shortness** means that the metal is brittle when cold.

Metals with percentage elongation less than 5% are brittle in behaviour.

Brittleness generally has no practical use in engineering and is mostly an undesirable property of the materials. Brittleness is useful to some extent in preparation of metal powders for powder metallurgy purposes.

6. Malleability. The property of a material of getting permanently deformed by compression without rupture is known as **malleability**.

In other words, it is the property of a material of being rolled or hammered to thin sheets.

Malleability requires that the material should be plastic, but it is not so dependent on strength.

The common metals in the decreasing order of their malleability by hammering are:

- | | | | |
|-----------|---------------|-----------------|-------------|
| (i) Gold | (ii) Silver | (iii) Aluminium | (iv) Copper |
| (v) Tin | (vi) Platinum | (vii) Lead | (viii) Zinc |
| (ix) Iron | (x) Nickel. | | |

This property is useful in the rolling and forging of the metals without rupture.

7. Hardness. The ability of a material to withstand scratching, wear and abrasion, or indentation (penetration) by harder bodies is known as **hardness**.

In case of metals, it is usually measured by determining the resistance to indentation, as by Brinell, Rockwell, Vickers, and Scleroscope hardness testing machines. The values of hardness obtained by these different methods are to some extent related to each other, and to the ultimate tensile strength of non-brittle (*i.e.* ductile) materials.

In case of minerals, hardness is the resistance which a mineral offers to abrasion. The absolute hardness is measured with the help of a sclerometer. The comparative hardness is expressed in terms of Moh's scale, and is determined by testing with ten standard minerals. These minerals, in the increasing order of their hardness on the original Moh's scale are as follows:

- | | | | |
|---------------|-----------------|---------------|---------------|
| (i) Talc | (ii) Gypsum | (iii) Calcite | (iv) Fluorite |
| (v) Apatite | (vi) Orthoclase | (vii) Quartz | (viii) Topaz |
| (xi) Corundum | (x) Diamond. | | |

Thus, a mineral with Moh's hardness number '6' will scratch or abrade apatite, but will be scratched by quartz.

A property opposite to hardness is **softness**. Materials normally become soft on heating, *i.e.*, their hardness reduces on being heated.

Hardness as ability to withstand wear, abrasion or scratching is useful for limit gauges used in engineering production, dies and punches, bearing surfaces in ball and roller bearings, case-hardened surfaces of various shafts etc. In the form of cutting ability or resistance to indentation, it is desirable in cutting tools for all metals and other materials, *e.g.*, lathe tools, milling cutters, drills, saws files, hacksaw blades etc.

8. Toughness. The amount of energy that a material can absorb before its fracture by impact load is known as its **toughness**.

It is also known as the relative degree of resistance of a material to impact.

It is indicated in tensile test by a high ultimate tensile strength and moderate elongation and reduction in area. It is also associated with high values in notched bar test (*i.e.* impact test). For ductile materials, an approximate measure of toughness, taken as the product of ultimate strength and elongation, is used for the purpose of comparison and is

called the **merit number**. Toughness is a measure of what may be called the **ultimate energy strength** of a material. Toughness may be expressed in terms of work units per unit of volume. For carbon steels, values range from 0.69 GJ/m³ to 11.67 GJ/m³; medium carbon steels are the toughest. Toughness can also be estimated in terms of area under the stress-strain diagram for the material. Toughness is also determined through impact test on an Impact Testing Machine.

The value of toughness is of importance in the selection of a material for type of services where impact loads are applied which from time to time may cause stresses above the elastic limit or yield point, *e.g.* anvil of power or drop hammer, power press punch, pneumatic hammer, etc.

9. Stiffness. The property concerned with relative deformability of a material under load is called **stiffness**.

Stiffness is measured by the rate of stress with respect to strain. Greater the stress; required to produce a given strain stiffer the material is said to be. Modulus of elasticity of a material refers to its stiffness in the elastic range. Stiffness is also expressed as stress produced in a material per unit of deformation under load. The term **flexibility** is sometimes used as opposite of stiffness. However, flexibility usually is concerned with flexure or bending. Also, it may mean ease of bending in plastic range.

Stiffness of a material is given due consideration while selecting the material for a component of a machine or a member of a structure. Stiffness is made use in graduating spring balances and spring controlled measuring devices.

10. Creep. The slow and continuous deformation of a material under steady load is known as **creep**.

Creep is shown by iron, nickel, copper and their alloys at elevated temperature. But zinc, lead, tin and their alloys show creep at room temperature even.

Creep limit is defined as maximum stress that will result in creep at a rate lower than some assigned rate. The test to find out creep limit of a material is carried out on a Creep Test Apparatus for a duration generally not less than 100 hours.

This property is given due consideration while designing I.C. engine, boiler and turbine components which are subjected to raised temperatures for long periods in their working conditions.

11. Endurance and Fatigue. The property of a material to withstand repeated application of stress is known as **endurance**.

The failure of a material caused under repeated loads (or stresses) is known as **fatigue** or **fatigue failure**.

The **endurance limit** or **fatigue strength** is the maximum value of stress that can be applied for indefinitely large number of times without causing failure. For ordinary steels the endurance limit under reversed flexure is roughly half the tensile strength. This value of Endurance Limit is determined with the help of a Fatigue Testing Machine.

Fatigue may be affected by static force or by impact applied repeatedly. The break occurs without any external manifestation of the approaching rupture. In this sense, it may be said that fatigue produces a brittle fracture.

Fatigue may be produced by different kinds of stresses; thermal bending, torsion, etc. where intermittent cycles of tension and compression are produced. It may also be associated with other destructive tendencies like notches, erosion, chafing or fretting etc., acting simultaneously with mechanical straining.

Fatigue failure in shafts and axles can be readily recognised by the appearance of the fracture which always displays concentric curve zones converging on a point (nucleus) from which rupture started. These roughly concentric zones are developed in successive stages of rupture formation.

In the design and production of parts of reciprocating machines and components subjected to vibrations, it is always desirable to keep the working stress well within the endurance limit of the material being used.

12. Resilience. The capacity of a material to absorb or store energy is known as its **resilience**.

The amount of energy absorbed in stressing a material upto elastic limit, or the amount of energy that can be recovered when stress is released from the elastic limit, is called the **elastic resilience**. The energy stored per unit volume at the elastic limit is the **modulus of resilience**. The modulus of resilience is a measure of what may be called the **elastic energy strength** of the material.

Resilience, especially modulus of resilience, is of vital importance in the section of materials for service where parts are subjected to energy loads but where stress must be kept within the elastic limit.

The Table 0.7 below gives values of important mechanical properties of some metals and alloys.

TABLE 0.7

<i>Metal</i>	<i>Ultimate Strength MPa</i>			<i>Elongation percent 5 cm</i>	<i>Brinell Hardness</i>	<i>Modulus of Elasticity Tension GP_a</i>	<i>Modulus of Rigidity GP_a</i>
	<i>Tension</i>	<i>Compression</i>	<i>Shear</i>				
Aluminium	88	225	80	29	21–24	70	–
Brass	160	68	100	64	70	59–98	34–39
Cast Iron	65–182	365–865	100	1	15–225	90–113	59–78
Copper	220	275	180	56	47	117	40
Duralumin	365	320	220	18	65	68.6	25.5
Mild steel	356–545	390	320	35	120	200–207	78
Wrought-Iron	220–410	245	245	35	100	176–196	73.5–93

MP_a = mega pascal = 10^6 N/m² = 1 N/mm².

GP_a = giga pascal = 10^9 N/m² = 10^3 N/mm².

0.13. PRESENT AND FUTURE NEEDS OF MATERIALS

As we see daily updates on international news, we see that developments will occur in high-speed trains and the infrastructural needs. To accommodate these, search of materials and their metallurgy will be challenging:

The **present era** of materials consist of aluminium and polymers. The high-volume production of an advanced aluminium chassis with a controlled solidification structure and excellent mechanical properties; it is lightweight and cost-effectiveness is presently in full usage in almost all fields ranging from infrastructure houses/cabins to aluminium alloys used in light weight engines and alloy wheels.

Polymers on the other hand are the cheapest material available these days. They have an advantage of formability from thinnest section (polythene) to lightest material. They are also used for thermal and electrical insulators. When combined with suitable elements give them excellent strength too. The only negative is the non-environmental friendly and its toxicity.

Future world needs will require materials that are **recyclable or biodegradable**. Natural plastics that are biodegradable will be used for packaging applications; these materials are made by fermentation of plant sugars and oils using microbial biofactories. A good example is a material made by Metabolix of Cambridge, Massachusetts, which is a semi-crystalline thermoplastic polymer. These natural plastics range in properties from stiff thermoplastics suitable for molded goods to highly elastic grades to grades suitable for adhesives and coatings. When exposed to microbial organisms the natural plastic breaks down enzymatically and decomposes.

Lightweight structural materials, specifically alloy development and processing, will be the focus of future materials (*i.e.*, foamed structures, magnesium-based components, and advanced aluminium alloys that can be selectively stiffened).

Future materials will certainly include innovative material uses such as **recyclable composites and bio-composites**. The hybrid-electric Model *U* developed by Ford makes extensive use of recyclable composites. Corn-based materials are used in the interior roof fabric and floor matting, while soy and corn-derived resins replace carbon black in the tires. The synthetic polyester used to cover seats and door panels can also be recycled back to polyester.

The future materials characteristics will be focused on

- Strong and lightweight materials,
- Sustainability,
- Material recyclability

- Less energy usage for forming
- Materials with reduced environmental effect throughout life cycle
- Increased recirculation of materials
- Bio-derived materials

will be some of the major factors influencing the development of future materials.

0.14. ECONOMIC CONSIDERATIONS IN USAGE OF MATERIALS

The manufactured product must be such that it must be a saving for customers as well companies may also profit from it.

To minimize product cost materials engineers must consider three factors

- (i) Design of product
- (ii) Material selection
- (iii) Manufacturing techniques

Economics of engineering/manufacture a component/system depends on three factors:

- **Component design:** Manufacturing of a component starts from conception, design, material selection.
- **Material usage life cycle:** The design must be based on “Green Design”—which means REDUCE/REUSE/RECYCLE the material. But these green design are also with negative economics of recovery cost. Material life starts from extraction, forming into a component, service, disposal and sometimes the recyclability for converting to other useful products after completion of a complete life cycle of that product.
- **Manufacturing costs:** It includes Direct labor cost and indirect labor cost overheads. It must be made a choice whether to manufacture the product/sub-contract purchase. Inspection, packing, and transportation adds onto the increase the cost of a product.

All these three factors are inter-related *i.e.*, one or two might influence the choice of others.

0.15. ENVIRONMENTAL CONSIDERATIONS

Manufacturing of a product does have impact on environment in many ways. This is because resources required to produce a product comes from different parts of the world. Along with these, negative effects of industrialization is now of major issue in various parts of the world. A material used to produce a product goes through number of

stages/phases. As already said, the design must be based on “Green Design”-which means REDUCE/REUSE/RECYCLE the material.

Reduce: Redesign the product to use less material.

Example: PET bottles with thinner walls.

Reuse: Fabricate the product of a material that can reused.

Example: refillable bottles and shipping containers.

Recycle: Reprocess the material into a new product.

Example: convert PET bottles to carpet fibers.

Advantage of the recycling is reduced pollution emission due to energy used in disposal of the product. Most of the metals are recyclable are energy efficient, produce less waste pollution. But metals like Cadmium and Hg are toxic, so are hazardous to handle. Polymers and Glass are also recyclable, but polymers loose their properties and are toxic too. Hence, a new generation Polymers are more in demand, Current generation based on biorenewable materials such as poly (lactic acid) (PLA). After commercial composting they decompose to nutrient fully in month.

0.16. SOCIAL ISSUES

- Raw materials and energy are prime cost components for manufacturing a product.
- However, they are limited in nature. Hence, materials and energy need to conserved.
- Material life cycle involves interactions and exchanges among materials, energy and the environment including the society.
- Social issues of material usage relates to weather distribution, and safe waste disposal.
- Products are needed to be designed and manufactured such that they are environmentally friendly, and easy to recycle. In case of disposal into environment, products need to be bio-degradable.

0.17. BIO-MATERIALS

There are many kinds of materials with different applications. In this context, biomaterials stand out because of their ability to remain in contact with tissues of the human body. Biomaterials covers fields of medicine, biology, chemistry, and materials science. Biomaterials have been used for several applications, such as joint replacements, bone plates, bone cement, artificial ligaments and tendons, dental implants for tooth fixation, blood vessel prostheses, heart valves, artificial tissue, contact lenses, and breast implants.

Definitions of Bio materials

A biomaterial is a nonviable material used in a medical device intended to interact with biological systems (Williams 1987).

Courey defines biomaterial to be “*a structural material, derived from synthetic or natural sources, that interacts with tissue for medical therapeutic or diagnostic purposes.*”

A biomaterial is defined as any systemically, pharmacologically inert substance or combination of substances utilized for implantation within or incorporation with a living system to supplement or replace functions of living tissues or organs.

A material intended to interface with biological systems to evaluate, treat, augment or replace any tissue, organ or function of the body.

In general, all biomedical materials belong to one of following categories:

1. Biological materials,
2. Polymers,
3. Ceramics,
4. Metals or
5. Composites.

Important aspects of research activities in this area encompasses principles of materials science and mechanical properties, some of which are fatigue, creep, mathematical models of materials, wear, lubrication, testing methodology, standardization, etc.

A number of materials have been developed to allow repair or replacement of tissue.

Characteristics of Bio Materials

- They must be *bio-compatible* and, in some cases, able to *stimulate cell growth*.
- They must *resist attack by body fluids* or, if attacked, it must be in a way that allows the body to *absorb the corrosion products* fastly.
- They must also meet *demanding mechanical constraints*: particularly the ability to carry the cyclic loads imposed on them by the normal functioning of the body, and to do so for many years.
- They carry *FDA and other approvals* to permit their use.

0.18. DESIRED PROPERTIES OF BIOMATERIALS

A biomaterial should satisfy the criteria given below.

Mechanical properties: Stress shielding can be prevented by matching the modulus of elasticity of biomaterials to that of bone, which varies from 4 to 30 GPa (12,13). Additionally, the material should

have a low modulus combined with high strength to prolong the service period of the implant and prevent loosening, thereby preventing the need for revision surgery.

Biocompatibility: The developed material should be compatible with living systems and not cause any bodily harm, which includes all of the negative effects a material can have on the components of a biological system (bone, extra and intracellular tissues, and ionic composition of plasma)

High wear resistance: The material should have a high wear resistance and exhibit a low friction coefficient when sliding against body tissues. An increase in the friction coefficient or a decrease in the wear resistance can cause the implant to loosen (14,15). Moreover, the wear debris generated can cause inflammation that is destructive to the bone supporting the implant.

High corrosion resistance: An implant that is made of a biomaterial with a low corrosion resistance can release metal ions into the body, which in turn produces toxic reactions.

Osseointegration: Osseointegration was first defined as “a direct structural and functional connection between ordered, living bone and the surface of a load-carrying implant”.

The roughness, chemistry, and topography of the surface play a major role in good osseointegration. Implant loosening results from the non-integration of the implant surface into the adjacent bone. Few researchers mention that osseointegration is undesirable due to the risk of not being able to remove the implant after use. However, a few of them have also demonstrated that the implant could be removed safely. Thus osseointegration is a desirable.

0.18.1 Applications of Biomaterials

Biomaterials are used in:

- Joint replacements
- Bone plates
- Bone cement
- Artificial ligaments and tendons
- Dental implants for tooth fixation
- Blood vessel prostheses
- Heart valves
- Skin repair devices
- Cochlear replacements
- Contact lenses

0.19. SEMICONDUCTING MATERIALS

Conductor: Any material that will support a generous flow of charge when a voltage source is applied across its terminals.

Insulator: A material that offers a very low level of conductivity under pressure from an applied voltage source.

Semiconductor: A material that has a conductivity level somewhere between a conductor and an insulator.

Bohr model of an atom described that the electrons move around the nucleus in circles. Atomic structure of a material determines its ability to conduct or insulate. The orbit paths of the valence shell surrounding the nucleus are called shells. Each shell has a defined number of electrons it will hold.

Ex: Copper: 2.8.18.1 (1 electron valence)

The outer shell is called the valence shell. The less complete a shell is filled to capacity the more is conductive the material is. Copper has only 1 valence electron making it conductor and Silicon has 4 valence electrons making it semiconductor.

Intrinsic Semiconductors

- Intrinsic materials are those semiconductors that have been carefully refined to reduce the impurities to a very low level Ideally 100% pure material
- Semiconductors can be grouped into two categories:
 - Elemental semiconductors
- Silicon (Si)
 - Most common semiconductor used today
- Germanium (Ge)
 - First semiconductor used in p-n diodes
 - Compound semiconductors
- Gallium Arsenide (GaAs), Gallium Nitride (GaN)
- Silicon Carbide (SiC)

There are boundary levels and maximum energy states in which any electron in the atomic lattice can find itself, and there remains the forbidden region between the valence band and the ionization level.

Ionization is the mechanism whereby electron can absorb sufficient energy to break away from the atomic structure and enter the conduction band.

Valence band Energy gap is measured in electron volt (eV).

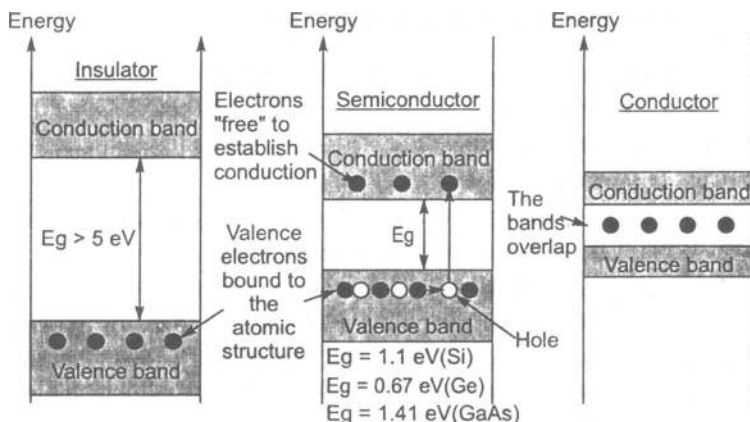


Fig. 0.8

Extrinsic Semiconductors

The characteristics of semiconductor materials can be altered significantly by the addition of certain impurity atoms into the relatively pure semiconductor material. These impurities, although only added to perhaps 1 part in 10 million, can alter the band structure sufficiently to totally change the electrical properties of the material. A semiconductor material that has been subjected to the doping process is called extrinsic semiconductor.

There are two types of extrinsic semiconductors: *n*-type and *p*-type.

Phosphorous – Donor Impurity in Si.

Phosphorous (P) replaces a Si atom and forms four covalent bonds with other Si atoms. This process will create *n*-type Si, since its electrical conductivity is the result of an excess concentration of negatively charged mobile carriers (electrons in the conduction band).

Boron – Acceptor Impurity in Si

Boron (B) replaces a Si atom and forms only **three** covalent bonds with other Si atoms. This process will create *p*-type Si, since its electrical conductivity is the result of an excess concentration of positively charged mobile carriers (holes in the valence band).

Why semiconductor is used for electronic device?

(i) Their material characteristics can be changed significantly through the process known as “doping”.

“Doping” is a process of adding impurity into semiconductor material. That material can be changed from poor conductor to a good conductor of electricity.

(ii) Their characteristics can be altered significantly through the application of heat or light an important consideration in the development of heat and light sensitive devices.

0.20. RECENT DEVELOPMENTS

0.20.1 Fibreglass and Fibreglass Composites

The first modern production method for fibreglass was patented by Dubus-Bonnel of France in 1836. In 1870 John Player developed a steam jet process to mass produce fibreglass – which he called mineral wool – as an insulation material. In 1936 Corning Glass in partnership with Owens-Illinois produced further developed the product and commenced production. In 1941 they produced fibreglass cloth. Carlton Ellis had patented polyester resin for Du Pont in 1936 and this was found suitable for making fibreglass composites.

Fibreglass is now in most family homes either as an insulation material or in composite form as items such as baths, shower cubicles, and wash basins. They are also often used for the hulls of leisure boats and for car bodies.

0.20.2 Donald Stookey's photochromic glass

A number of significant discoveries were made by Donald Stookey of Corning Glass. In 1948 he developed the photochemically machinable glass, 'FOTOFORM'. This was glass that when exposed to light through a patterned mask and subsequently to a particular solvent, the parts of the glass that had been exposed to light dissolved completely.

In 1959 he discovered photochromic glass—a material which would reversibly darken when light fell on it and become clear when it did not. This material is widely used for sunglasses.

0.20.3. Fibre optics

In 1960, following the discovery of the laser and the observation that light will travel along a glass fibre, the new field of fibre optics was born. A fibre optic cable uses rapid light pulses to transmit huge amounts of data with negligible energy loss. A 3000 km fibre optic transatlantic telephone cable first went into operation in 1988. It was designed to handle a mix of information and its installation was preceded by extensive underwater trials. However in 1991 the new field of photonic crystals led to the development of the photonic crystal fibre which can be designed to carry more power than a conventional fibre. They became commercially available in 1996.

REVIEW QUESTIONS

1. (a) What is the importance of the knowledge of "Materials and Metallurgy" to an engineer?
(b) What is the difference between metal and non-metal?
2. What is the difference between ferrous and non-ferrous metals?
3. What is alloy? Name any five alloys.
4. Define metals and non-metals. Give their comparison.
5. Define and explain physical properties of materials.
6. Define and explain mechanical properties of materials.
7. Write down short notes on (i) Electrical conductivity (ii) Thermal conductivity (iii) Corrosion.
8. Define the following terms and name the machines by which these are tested:
(i) Hardness of metals (ii) Toughness of metals.
9. Define the following properties of metals:
(i) Plasticity (ii) Malleability
(iii) Brittleness (iv) Ultimate tensile strength
(v) Toughness (vi) Stiffness
(vii) Elasticity (viii) Resilience
(ix) Creep (x) Fatigue.
10. What do you understand by the term 'corrosion'? Suggest some methods for preventing corrosion.
11. Define and explain the following terms:
(i) Melting point (ii) Density
(iii) Lustre.
12. Why are copper utensils used for heating water?
13. Why copper/aluminium conductors are used for transmission of electricity?
14. What happens if a piece of iron is kept in open moist weather?
15. Name any three metals/alloys which have good corrosive resistance.
16. What are the basis of classifying materials as metals, non-metals and metalloids? Write about physical, mechanical and corrosion properties of materials?
17. Write short notes on: (a) Electrical properties (b) Thermal properties.
18. Answer the following in 'yes' or 'no':
(a) Mercury is a non-metal.
(b) Copper is an alloy.
(c) Rubber band is more elastic than steel wire.
(d) Lead is a good conductor of electricity.
(e) Graphite is an insulator of electricity.
(f) Glass is not ductile.
(g) Aluminium is heavier than iron.

- (h) Steel is an alloy.
- (i) Cast iron is heavier than aluminium.
- (j) Cast iron is heavier than copper.
- 19. State the purposes of testing of metals.
- 20. Sketch and describe (a) tensile test (b) compression test of a metal.
- 21. Sketch and describe stress-strain curve for a ductile metal.
- 22. Sketch and describe the following hardness tests:
 - (i) Brinell hardness test
 - (ii) Rockwell hardness test
 - (iii) Vicker's pyramid hardness test
- 23. (a) What is creep?
 - (b) Sketch and describe a creep test.
 - (c) Describe creep curve.
- 24. (a) What is fatigue failure? Define endurance limit.
 - (b) State the factors which affect fatigue failure.
- 25. Sketch and describe a fatigue test.
- 26. Compare ductile failure and brittle failure of materials.