Rashtreeya Sikshana Samithi Trust

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Department of Mechanical Engineering

Course Name: Elements of Mechanical Engineering

Course Code: 21ME15/25

I/II Semester

2021 Scheme

MODULE-II

Properties, Composition, and Industrial Application of Engineering Materials:

Metals-Ferrous: Tool steels and stainless steels. Non-ferrous /metals: aluminum alloys.

Ceramics- Glass, optical fiber glass, cermets. **Composites**- Fiber reinforced composites, Metal matrix Composites. Smart materials- Piezoelectric materials, shape memory alloys, semiconductors, and super-insulators.

Metal Joining Processes:

Soldering, Brazing and Welding: Definitions. Classification and methods of soldering, brazing, and welding. Brief description of arc welding, Oxy-acetylene welding, Introduction to

TIG welding and MIG welding.

Heat Transfer Applications:

Review of modes of Heat Transfer; Automobile Radiators; Condensers and evaporators of refrigeration systems; Cooling of Electrical and Electronic Devices; Active, Passive, and Hybrid

Cooling.

Contents

2.1 PROPERTIES, COMPOSITION AND INDUSTRIAL APPLICATIONS OF ENGINEERING MATERIALS

All metals may be classified as ferrous or nonferrous. A ferrous metal has iron as its main element. Metal is still considered ferrous even if it contains less than 50 percent iron, as long as it contains more iron than any other one metal. A metal is nonferrous if it contains less iron than any other metal.

1. **Ferrous metals**

Ferrous metals contain iron. Examples are cast iron, mild steel, medium carbon steel, high carbon steel, stainless steel, and high-speed steel.

Composition, properties and uses of some common ferrous metals

Table. 2.1 Composition, properties and uses of some common ferrous metals

Name	Composition	Properties and characteristics	Principal uses
Cast iron	*Alloy* of iron and 2-5% carbon, 1-3% silicon and traces of magnesium, sulphur and phosphorus.	*Hard* skin, softer underneath, but *brittle*. It *corrodes* by rusting.	Parts with complex shapes which can be made by casting
Mild steel	Alloy of iron and 0.15 - 0.3% carbon	*Tough*, *ductile* and *malleable*. Good *tensile strength*, poor resistance to *corrosion*	General-purpose engineering material
Medium carbon steel	Alloy of iron and 0.35 - 0.7% carbon	*Strong*, hard and tough, with a high tensile strength, but less ductile than mild steel.	Springs; any application where resistance to wear is needed
High carbon steel	Alloy of iron and carbon: 0.7 - 1.5% carbon	Even harder than medium carbon steel, and more brittle. Can be heat-treated to make it harder and tougher	Cutting tools, mechanical elements
Stainless steel	Alloy of iron and carbon with 16-26% chromium, 8-22% nickel and 8% magnesium	Hard and tough, resists wear and corrosion	Cutlery, kitchen equipment
High speed steel	Alloy of iron and 0.35 - 0.7% carbon (medium carbon steel) with tungsten, chromium, vanadium, and sometimes cobalt	Very hard, high *abrasion*- and heat-resistance	Cutting tools for machines

2. **Non-ferrous metals**

Non-ferrous metals do not contain iron. Some common non-ferrous metals are aluminum, copper, zinc, tin, brass (copper + zinc), and bronze (copper + tin).

Composition, properties, and uses of some common non-ferrous metals:

Table. 2.2 Composition, properties and uses of some common n o n - ferrous metals

Name	Composition	Properties and characteristics	Principal uses
Aluminium	Pure aluminium (an element)	Good *strength*-to-weight ratio, light, soft, *ductile*, good *conductor* of heat and electricity	Kitchen equipment, window frames, general cast components
Copper	Pure copper (an element)	*Malleable* and ductile, good conductor of heat and electricity, resistant to *corrosion*	Water pipes, electrical wire, decorative goods
Zinc	Pure zinc (an element)	Weak metal, extremely resistant to corrosion	Usually used for coating steel to make galvanised items
Brass	*Alloy* of copper and zinc	Resistant to corrosion, fairly hard, good conductor of heat and electricity	Cast items such as water taps, ornaments
Bronze	Alloy of copper and tin	Fairly strong, malleable and ductile when soft	Decorative goods, architectural fittings
Tin	Pure tin (an element)	Soft, weak, malleable, ductile and resistant to corrosion	Usually used for coating steel to form tinplate

2.2 Engineering Materials

2.2.1 Introduction

Materials are an important aspect of engineering design and analysis. The importance of materials science and engineering can be noted from the fact that historical ages have been named after materials. In the customer-driven competitive business environment, the product quality is of paramount importance. The product quality has been found to be influenced by the engineering design, type of materials selected and the processing technology employed.

Therefore, the importance of materials and their processing techniques cannot be undervalued in today's world. Materials form the stuff of any engineering application or product. It has been found that the engineers do not give adequate attention to this important subject. Moreover, it has not been adequately represented in the course curriculum of various universities. Therefore, it becomes imperative to highlight the importance of engineering materials for all engineers related to the various aspects of engineering applications.

There is a wide variety of materials available which have shown their potential in various engineering fields ranging from aerospace to household applications. The materials are usually selected after considering their characteristics, specific application areas, advantages, and limitations. The challenge for designers is to select an optimal material suitable for the specific design requirements. The stringent design requirements generally lead to the development of new materials to meet the specific operating conditions and environments. The new materials are developed from the conventional materials by either by the intrinsic or the extrinsic modification. In an intrinsic modification, minor alloying or heat treatment is carried out. In an extrinsic modification, external reinforcements are added to the parent material to alter its properties in order to meet the specific design requirements.

2.2.2 Classification and Selection of Materials:

The first module deals with the classification of the engineering materials and their processing techniques. The engineering materials can broadly be classified as:

a) Ferrous Metals

b) Non-ferrous Metals (aluminum, magnesium, copper, nickel, titanium)

c) Plastics (thermoplastics, thermosets)

d) Ceramics and Diamond

e) Composite Materials

f) Nano-materials

## Classification of Processing Techniques

The basic aim of processing is to produce the products of the required quality at a reasonable cost. The basic processes can be broadly classified as:

a) Primary Forming Processes

b) Deformation Processes

c) Material Removal Processes d) Joining Processes

e) Finishing Processes

Most of the engineering materials are processed either individually or in combination with the above-mentioned processes. The processes can further be classified as conventional and advanced p r o c e s s e s . The s p e c i f i c application area of each w i l l d e p e n d on t h e design requirements and the ability with which a material renders itself to various processing techniques. The selection of a processing technique for any engineering material would broadly depend on the properties (mechanical, physical, chemical) of the material and the required number of parts to be processed.

2.3 Composites

A composite material is made by combining two or more materials – often ones that have very different properties. The two materials work together to give the composite unique properties. However, within the composite, you can easily tell the different materials apart as they do not dissolve or blend into each other. Fig. 2.1 shows the classification of composite materials.
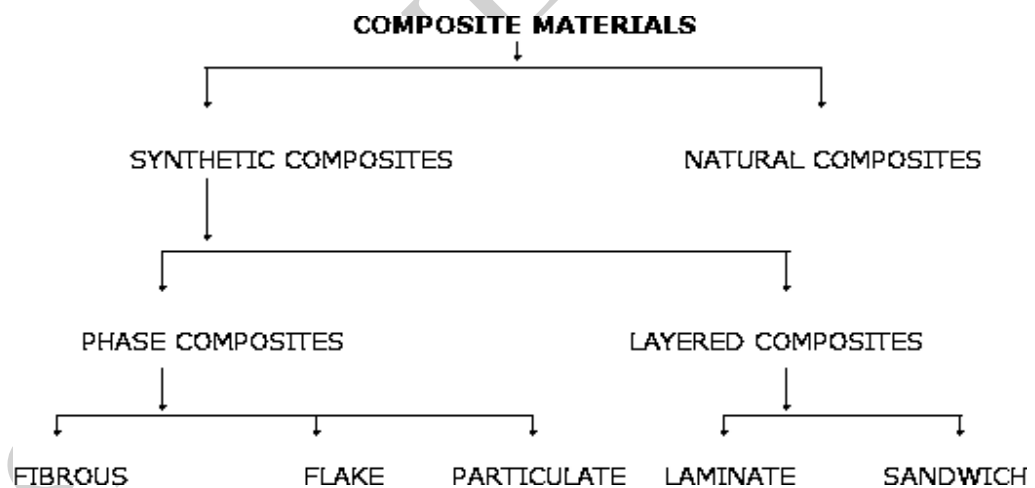
Fig. 2.1 classification of composite materials

2.3.1 Classification of composites I (based on matrix material)

i) Metal Matrix Composites (MMC)

Metal Matrix Composites are composed of a ==metallic matrix== (aluminum, magnesium, iron, cobalt, copper) and a ==dispersed ceramic== (oxides, carbides) or ==metallic== (lead, tungsten, molybdenum) phase.

ii) Ceramic Matrix Composites (CMC)

Ceramic Matrix Composites are composed of a ==ceramic matrix== and ==embedded fibers of other ceramic material== (dispersed phase).

iii) Polymer Matrix Composites (PMC)

Polymer Matrix Composites are composed of a ==matrix from thermoset== (Unsaturated Polyester (UP), Epoxy (EP)) ==or thermoplastic== (Polycarbonate (PC), Polyvinylchloride, Nylon, Polystyrene) and ==embedded glass, carbon, steel or Kevlar fibers== (dispersed phase).

Classification of composite materials II (based on reinforcing material structure)

Particulate Composites

Particulate Composites consist of a matrix reinforced by a dispersed phase in the form of particles.

1. Composites with random orientation of particles.
2. Composites with preferred orientation of particles. Dispersed phase of these materials consists of two-dimensional flat platelets (flakes), laid parallel to each other.

Fibrous Composites

1. Short-fiber reinforced composites. Short-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in the form of discontinuous fibers (length < 100*diameter).
I. Composites with random orientation of fibers.
II. Composites with preferred orientation of fibers.
2. Long-fiber reinforced composites. Long-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in the form of continuous fibers.
I. Unidirectional orientation of fibers.

II. The bi-directional orientation of fibers (woven).

Laminate Composites

When a fiber-reinforced composite consists of several layers with different fiber orientations, it is called multilayer (angle-ply) composite.

Composites

Fibers or particles embedded in a matrix of another material are the best examples of modern-day composite materials, which are mostly structural.

Laminates are composite material where different layers of materials give them the specific character of a composite material having a specific function to perform. Fabrics have no matrix to fall back on, but in them, fibers of different compositions combine to give them a specific character. Reinforcing materials generally withstand maximum load and serve the desirable properties.

Further, though composite types are often distinguishable from one another, no clear determination can be really made. To facilitate the definition, the accent is often shifted to the levels at which differentiation take place viz., microscopic or macroscopic.

In matrix-based structural composites, the matrix serves two paramount purposes viz., binding the reinforcement phases in place and deforming to distribute the stresses among the constituent reinforcement materials under an applied force.

The demands of matrices are many. They may need to temperature variations, be conductors or resistors of electricity, have moisture sensitivity, etc. This may offer weight advantages, ease of handling and other merits which may also become applicable depending on the purpose for which matrices are chosen.

Solids that accommodate stress to incorporate other constituents provide strong bonds for the reinforcing phase are potential matrix materials. A few inorganic materials, polymers, and metals have found applications as matrix materials in the designing of structural composites, with commendable success. These materials remain elastic until failure occurs and show decreased failure strain when loaded in tension and compression.

Classification of Composites

Composite materials are commonly classified at following two distinct levels:

- The first level of classification is usually made with respect to the matrix constituent. The major composite classes include Organic Matrix Composites (OMCs), Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs). The term organic matrix composite is generally assumed to include two classes of composites, namely Polymer Matrix Composites (PMCs) and carbon matrix composites commonly referred to as carbon-carbon composites.

- The second level of classification refers to the reinforcement form - fiber-reinforced composites, laminar composites, and particulate composites. Fiber Reinforced composites (FRP) can be further divided into those containing discontinuous or continuous fibers.

- Fiber Reinforced Composites are composed of fibers embedded in the matrix material. Such a composite is considered to be a discontinuous fiber or short fiber composite if its properties vary with fiber length. On the other hand, when the length of the fiber is such that any further increase in length does not further increase, the elastic modulus of the composite, the composite is considered to be continuous fiber- reinforced. Fibers are small in diameter and when pushed axially, they bend easily although they have very good tensile properties. These fibers must be supported to keep individual fibers from bending and buckling.

- Laminar Composites are composed of layers of materials held together by matrix. Sandwich structures fall under this category.

- Particulate Composites are composed of particles distributed or embedded in a matrix body. The particles may be flakes or in powder form. Concrete and wood particle boards are examples of this category.
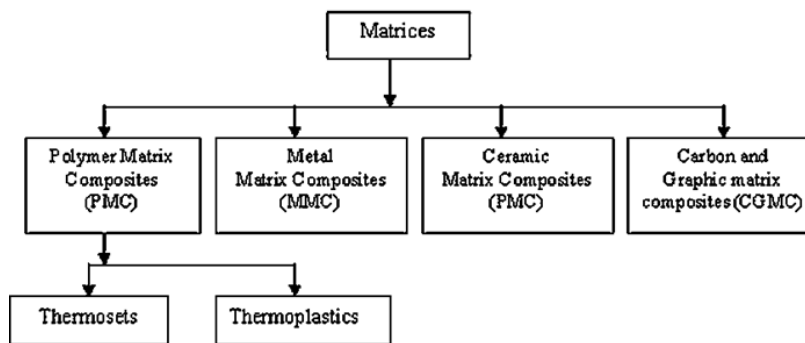
Fig. 2.2 classification of matrices

Organic Matrix Composites

Polymer Matrix Composites (PMC)/Carbon Matrix Composites or Carbon-Carbon Composites

Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. It follows, therefore, that high- temperature resins are extensively used in aeronautical applications.

Two main kinds of polymers are thermosets and thermoplastics. Thermosets have qualities such as a well-bonded three-dimensional molecular structure after curing. They decompose instead of melting on hardening. Merely changing the basic composition of the resin is enough to alter the conditions suitably for curing and determine its other characteristics. They can be retained in a partially cured condition too over prolonged periods of time, rendering Thermosets very flexible. Thus, they are most suited as matrix bases for advanced conditions fiber- reinforced composites. Thermosets find wide-ranging applications in the chopped fiber composites form particularly when a premixed or molding compound with fibers of specific quality and aspect ratio happens to be starting material as in epoxy, polymer, and phenolic polyamide resins.

Thermoplastics have one- or two-dimensional molecular structure and they tend to at an elevated temperature and show the exaggerated melting point. Another advantage is that the process of

softening at elevated temperatures can be reversed to regain its properties during cooling, facilitating applications of conventional compress techniques to mold the compounds.

Resins reinforced with thermoplastics now comprised an emerging group of composites. The theme of most experiments in this area to improve the base properties of the resins and extract the greatest functional advantages from them in new avenues, including attempts to replace metals in die-casting processes. In crystalline thermoplastics, the reinforcement affects the morphology to a considerable extent, prompting the reinforcement to empower nucleation. Whenever crystalline or amorphous, these resins possess the facility to alter their creep over an extensive range of temperature. But this range includes the point at which the usage of resins is constrained, and the reinforcement in such systems can increase the failure load as well as creep resistance. Figure M1.2.1 shows kinds of thermoplastics.

Metal Matrix Composites (MMC)

Metal-matrix composites (MMCs) typically use silicon carbide fibers embedded in a matrix made from an alloy of aluminum and magnesium, but other matrix materials such as titanium, copper, and iron are increasingly being used. Typical applications of MMCs include bicycles, golf clubs, and missile guidance systems; an MMC made from siliconcarbide fibers in a titanium matrix is currently being developed for use as the skin (fuselage material) of the US National Aerospace Plane.

Metal matrix composites, at present though generating a wide interest in research fraternity, are not as widely in use as their plastic counterparts. High strength, fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts. They can withstand elevated temperature in corrosive environment than polymer composites. Most metals and alloys could be used as matrices and they require reinforcement materials which need to be stable over a range of temperature and non-reactive too. However the guiding aspect for the choice depends essentially on the matrix material. Light metals form the matrix for temperature application and the reinforcements in addition to the aforementioned reasons are characterized by high moduli.

Most metals and alloys make good matrices. However, practically, the choices for low temperature applications are not many. Only light metals are responsive, with their low density proving an advantage. Titanium, Aluminium and magnesium are the popular matrix metals currently in vogue, which are particularly useful for aircraft applications. If metallic matrix materials have to offer high strength, they require high modulus reinforcements. The strength-toweight ratios of resulting composites can be higher than most alloys.

The melting point, physical and mechanical properties of the composite at various temperatures determine the service temperature of composites. Most metals, ceramics and compounds can be used with matrices of low melting point alloys. The choice of reinforcements becomes more stunted with increase in the melting temperature of matrix materials..

Inorganic Material and their uses

Materials that do not contain the components associated with organic materials are called inorganic materials. Examples: Ceramics, glasses, refractories and composites

Ceramics: They are compounds of metallic and non-metallic elements. They are formed from inorganic as well as non-metallic materials such as silicates, oxides, carbides, nitrides and aluminates. Glass, porcelain, bricks, cements fluxes etc. are common examples. Ceramics are generally opaque but as an exception, yttralox is transparent and hence used for spectacles. Ceramics are used for manufacture of machine tools, insulators, semiconductors, floor and wall ties, crucibles, jars, components of chemical reactors etc.

Glasses: Glasses are transparent silica products which may be amorphous or crystalline depending on heat treatment. Hence, some varieties of glasses are grouped under organic materials. Glasses used in industries are broadly classified in to four types, namely, (i) soda lima glass, (ii) Lead glass, (iii) borosilciates glass and (iv) high silica glass.

Glasses are used for all types of insulation, partitions, and laminates, in all types of buildings, fire proof and acid proof fabrics, parts of automobile and aircrafts, mechanical gauges, medical and chemical equipments etc.

2.4 Smart Materials:
i) Piezoelectric materials:

- Materials that produce a voltage when stress is applied. (An applied mechanical stress will generate a voltage) – Fig. 2.3

- Example: Quartz,BaTiO3,GaPO4

- The piezoelectric effect describes the relation between a mechanical stress and an electrical voltage in solids.

- In physics, the piezoelectric effect can be described as the the link between electrostatics and mechanics.

- An LED is wired to a piezoelectric transducer. The LED briefly lights when the device is flicked & shows that electricity has been generated by stress and strain.
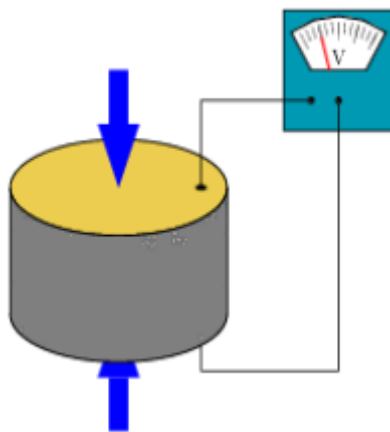
(a)   (b)

Fig. 2.3 shows the Illustration of piezoelectric effect

Reverse Piezoelectric effect:

- An applied voltage will change the shape of the solid by a small amount (up to a 4% change in volume) (Fig. 2.4). Quartz watches, Piezo electric US oscillator

- Applications of Piezo electric effect:

1. In lighters or portable sparkers with a piezo fuze a sudden and strong pressure is used to produce a voltage. The spark then ignites the gas.

2. A piezo motor is based on the change in mechanical shape of a piezoelectric material when an tension is applied. The material produces ultrasonic or acoustic vibrations and produces a linear or rotary motion.

3. Piezo elements are used in music for acoustic instruments. They are inserted in stringed instruments such as guitar, violin or Mandoline. The dynamic deformation/vibration of the cords is converted into a small alternating voltage.

(a)   (b)   (c)
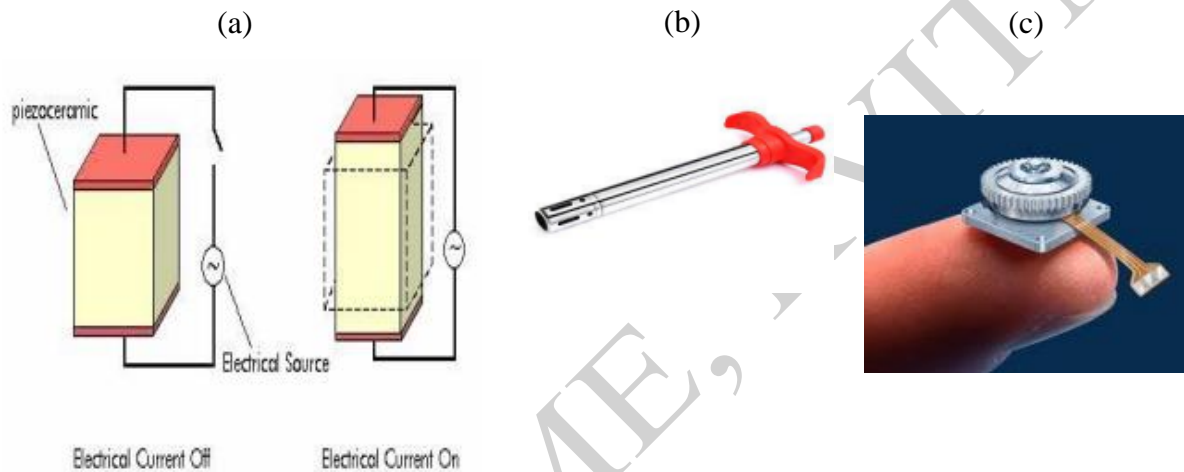
Fig. 2.4 shows the Illustration of reverse-piezoelectric effect

ii) Shape Memory Alloys (SMAs):

- An alloy that "remembers" its original, cold forged shape. By heating it returns back to the re-deformed shape (Fig. 2.5).

- SMAs are materials which can revert back to original shape & size on cooling by undergoing phase transformations.

- Examples: Thermal: NiTiNOL, Magnetic: NiMnGa, Fe-Pd, Terfenol-D, Actuator: CuZnSi, CuZnAl, CuZnGa, CuZnSn.

- Shape Memory Alloys (SMAs) are a unique class of metal alloys that can recover apparent permanent strains when they are heated above a certain temperature

- A phase transformation which occurs between these two phases upon heating/cooling is the basis for the unique properties of the SMAs.
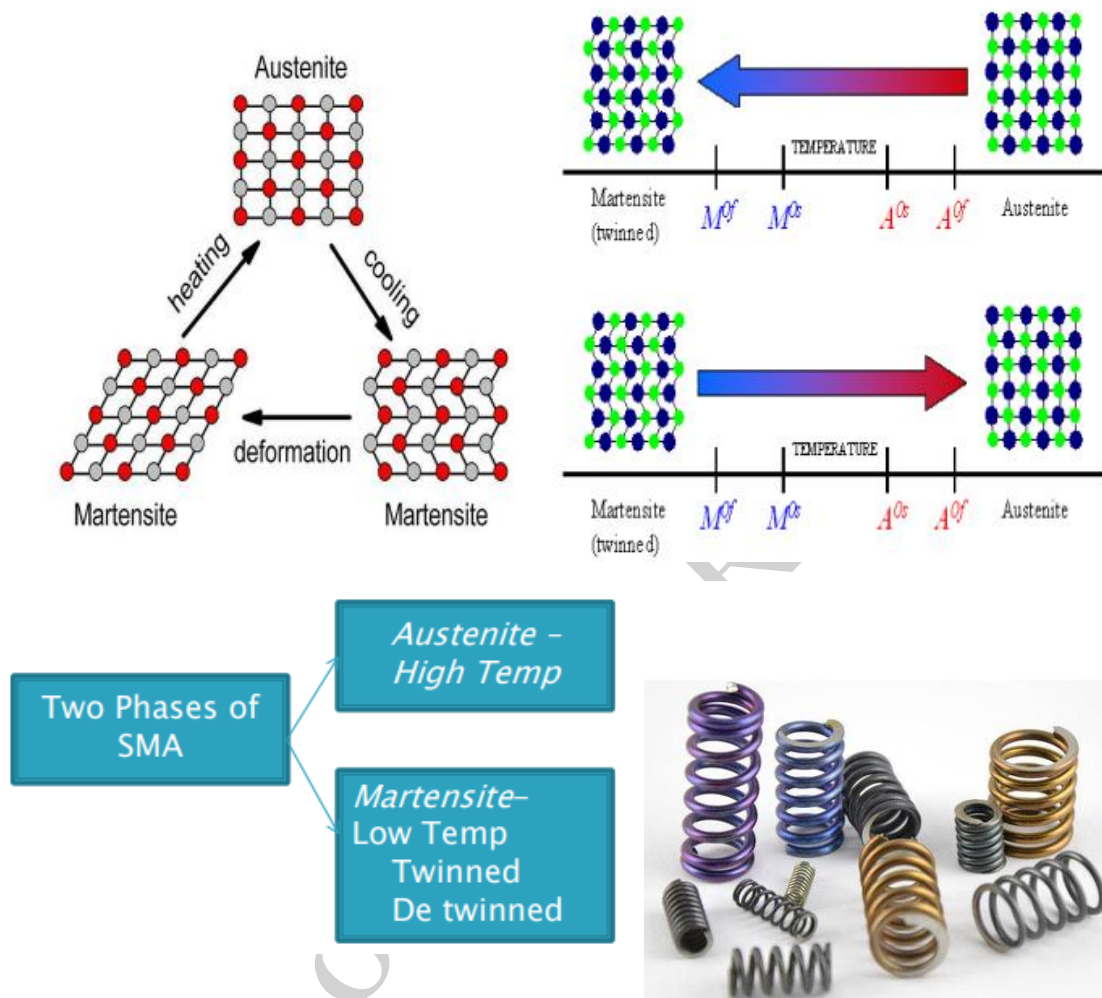
Fig. 2.5 shows the Illustration of reverse-piezoelectric effect

iii) Semiconductors:

Materials that permit flow of electrons are called conductors (e.g., gold, silver, copper, etc.). Materials that block flow of electrons are called insulators (e.g., rubber, glass, Teflon, mica, etc.). Materials whose conductivity falls between those of conductors and insulators are called semiconductors. Semiconductors are "part-time" conductors whose conductivity can be controlled. Silicon is the most common material used to build semiconductor devices. Si is the main ingredient of sand and it is estimated that a cubic mile of seawater contains 15,000 tons of

Si. Si is spun and grown into a crystalline structure and cut into wafers to make electronic devices.

Atoms in a pure silicon wafer contains four electrons in outer orbit (called valence electrons). Germanium is another semiconductor material with four valence electrons. In the crystalline lattice structure of Si, the valence electrons of every Si atom are locked up in covalent bonds with the valence electrons of four neighboring Si atoms. In pure form, Si wafer does not contain any free charge carriers. An applied voltage across pure Si wafer does not yield electron flow through the wafer. A pure Si wafer is said to act as an insulator. In order to make useful semiconductor devices, materials such as phosphorus (P) and boron (B) are added to Si to change Si's conductivity.

N-Type Semiconductor:

Trivalent impurities e.g., boron, aluminum, indium, and gallium have 3 valence electrons.

When boron is added to Si, every boron atom's three valence electrons are locked up in covalent bond with valence electrons of three neighboring Si atoms. However, a vacant spot "hole" is created within the covalent bond between one boron atom and a neighboring Si atom. The holes are considered to be positive charge carriers. When a voltage is applied across the silicon-boron mixture, a hole moves toward the negative voltage end while a neighboring electron fills in its place. When boron is added to Si to yield the above effect, we say that Si is doped with boron. The resulting mixture is called P-type silicon (P: positive charge carrier silicon). The trivalent impurities are referred to as acceptor impurities.

P-Type Semiconductor:

Atoms in a pure silicon wafer contains four electrons in outer orbit (called valence electrons). Germanium is another semiconductor material with four valence electrons. In the crystalline lattice structure of Si, the valence electrons of every Si atom are locked up in covalent bonds with the valence electrons of four neighboring Si atoms. In pure form, Si wafer does not contain any free charge carriers. An applied voltage across pure Si wafer does not yield electron flow through the wafer. A pure Si wafer is said to act as an insulator. In order to make useful

semiconductor devices, materials such as phosphorus (P) and boron (B) are added to Si to change Si's conductivity.

Super-insulator:

- A superinsulator is a material that at low but finite temperatures does not conduct electricity, i.e. has an infinite resistance so that no electric current passes through it.

- The superinsulating state is the exact dual to the superconducting state and can be destroyed by increasing the temperature and applying an external magnetic field and voltage.

- Both superconductivity and superinsulation rest on the pairing of conduction electrons into Cooper pairs. In superconductors, all the pairs move coherently, allowing for the electric current without resistance.

- In superinsulators, both Cooper pairs and normal excitations are confined and the electric current cannot flow.

- A mechanism behind superinsulation is the proliferation of magnetic monopoles at low temperatures. In two dimensions (2D), magnetic monopoles are quantum tunneling events (instantons) that are often referred to as monopole plasma. In three dimensions (3D), monopoles form a Bose condensate.

- Superinsulators could potentially be used as a platform for high-performance sensors and logical units. Combined with superconductors, superinsulators could be used to create switching electrical circuits with no energy loss as heat

2.5 JOINING PROCESSES: SOLDERING, BRAZING, AND WELDING

i) Soldering is a process in which two or more metal items are joined together by melting and flowing a filler metal (solder) into the joint.

• The filler metal will have a lower melting point than the workpiece **(between 150°C-350°C)**

• Soldering differs from welding in that **soldering does not involve melting the workpieces.**

• An alloy of lead & tin called '**soft solder'** is used for sheet metal work, plumbing work & electrical junctions.

• To clean the surfaces to be joined & to prevent oxidation, Zinc chloride is used as a flux.

• A soldering iron is used to apply heat produced from an electrical source. Fig. 2.6 (a) shows the soldering iron (b) soldering flux, (c) soldering wire.
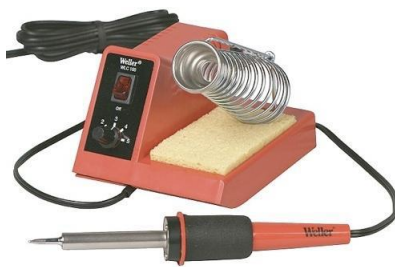
**Fig. 2.6 (a) Soldering iron   (b) soldering flux   (c) soldering wire**

ii) Brazing

• **Brazing** is a method of joining two similar or dissimilar metals using a special fusible alloy. (This melts above 450°C). It produces joints stronger than soldering. Fig. 2.7 shows the brazing process.

• The molten filler material flows into the joint space by capillary action and after cooling produce a strong joint.

• However, the base metal does not reach its melting temperature.

• The filler materials used in brazing are **copper base & silver base alloys.**

• The heat source is oxy-acetylene welding torch & the flux used is **borax (sodium borate) and mixtures of borax & boric acid.**
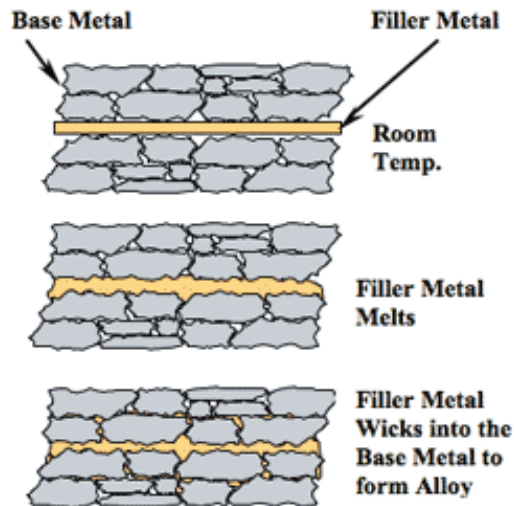
Fig. 2.7 brazing process

iii) Welding

• **Welding** is a process of joining two pieces of metal by the application of heat with or without the application of pressure and filler material.

• Welding produces a **permanent joint.**

• Welding is used in joining pressure vessels, tanks, bridges, railways, machine frames & brackets, building the body of automobiles, aircraft & ships, etc.

Welding process may be broadly classified as;

1. Plastic welding or **Pressure welding**

2. Fusion welding or **Non Pressure welding Plastic Welding (or) Pressure welding:** In this type of welding, the metal pieces to be joined are heated to a plastic state and then joined together by the application of pressure without the addition of filler material.

 Ex: Forge welding, Resistance welding.

Fusion welding (or) Nonpressure welding: In this type of welding, the metal pieces to be joined are heated to a molten state and allowed to solidify without the application of pressure. A filler material is used during the welding process. Fig. 2.8 displays the arc welding set up.

Ex: Arc welding, Gas welding, Thermit welding ARC WELDING
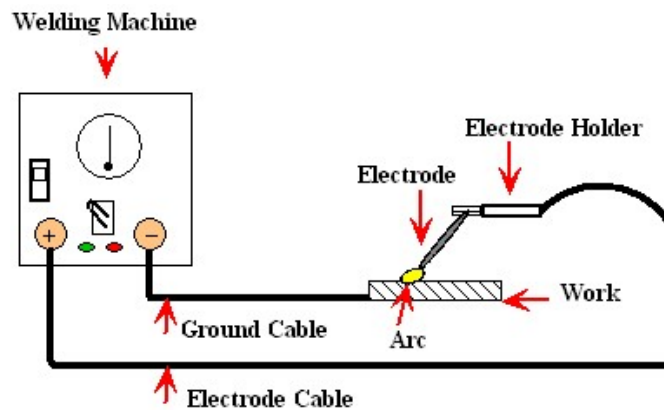
Fig. 2.8 Arc welding set up

• The principle of arc welding is that, when two conductors of an electric circuit are touched together momentarily and then instantaneously separated slightly, an electric arc is formed. Fig. shows 2.9 shielded metal arc welding process.

• A high heat density is produced throughout the length of the arc at a temperature of 5000 to 6000°C.

• The bare section at the end of the electrode is clamped to one terminal of the power source & the other terminal is connected to the workpiece being welded.

• The function of a welding machine is to generate a low voltage (10 to 50 V) and high current. (50 A to 300 A)

• The current may be alternating current or direct current & the polarity of the electrode may be positive or negative, depending on the type of electrode and the metals to be welded.

• In A.C arc welding, a **step-down transformer** is used to step down the voltage from 220/440 V to 80 to 100 V & current of 100 to 400 A.

• In D.C welding, the **workpiece** is connected to the +**ve pole** of a D.C generator and the **electrode** to –**ve pole.**

• It is called **'straight polarity'** and is used when high heat is required.

• When less heat is required, the polarity is reversed.

• Because of the option of reversing the polarity, D.C welding may be used to weld many metals which require more heat to melt.

• In A.C welding, the polarity changes in every cycle.

• Also, the current & the voltage acquire a value of zero twice in every cycle, and hence higher voltage is required to maintain the arc.
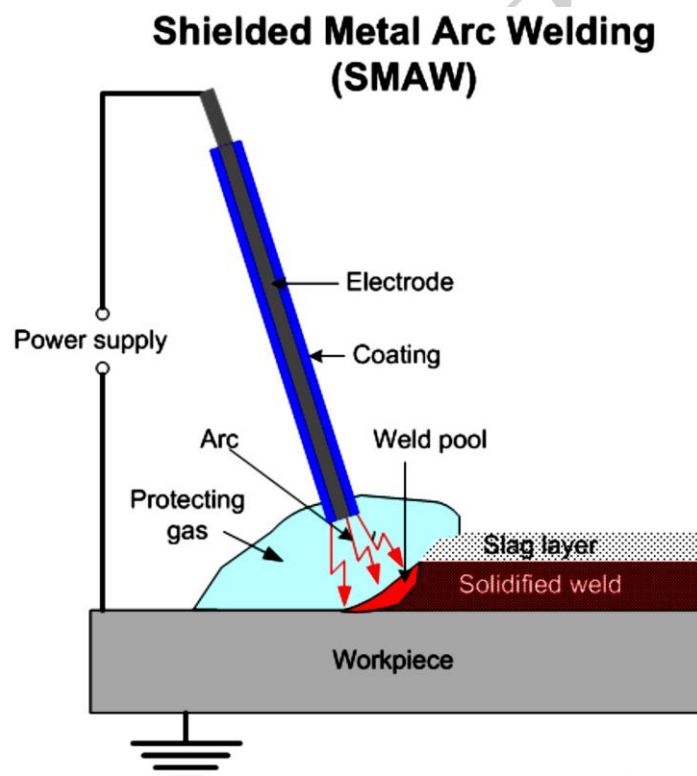
Fig. 2.9 Shielded metal arc welding process

• When the arc is struck, the intense heat quickly melts the workpiece and forms a small molten metal pool.

• At the same time, the electrode also melts and mixes with the base metal.

• A solid joint will be formed when the molten metal cools & solidifies.

• A **flux coating** over the electrode produces an inert gaseous shield and protects the molten metal from atmospheric oxidation.

Arc welding Electrodes

• The electrode used in arc welding is of consumable type & it is coated with flux.

• The flux coating is usually made of **chalk (lime), Ferromanganese, cellulose, Starch, Kaolin (China clay), iron powder, etc.**

• The flux forms a slag after welding which can be removed by chipping hammer & a wire brush.

• The purpose of coating the electrodes are;

(i) Protection of molten metal from oxidation (ii) To prevent rapid cooling of molten metal (iii) To establish & maintain the arc. (iv) Addition of alloying elements. **Purpose of each ingredient of flux coating**

• **China clay**, **mica,** etc. produce a slag which because of its lightweight forms a layer on the molten metal and protects the same from atmospheric contamination.

• Ingredients, like **cellulose, wood, starch**, calcium carbonate, etc., form a protective gas shield around the electrode end, arc and weld pool.

• Deoxidizing elements like **Ferro-manganese** refine the molten metal.

• Alloying elements like **Ferroalloys of manganese, molybdenum,** etc. may be added to impart suitable properties and strength to the weld metal.

• **Iron powder** in the coating improves arc behavior, bead appearance; helps increase metal deposition rate and arc travel speed.

Gas welding

• Gas welding is a fusion method of welding in which a strong gas flame is used to raise the temperature of the workpieces to melt them.

• As in arc welding, a filler material is used to fill the joint.

• The gas combinations that can be used for heating are;

1. **Oxygen & Acetylene**

2. **Oxygen & Hydrogen**

The oxy-acetylene gas mixture is most commonly used in gas welding. The temperature of gas welding is around 3500°C.

• The oxy-acetylene gas equipment consists of two large steel cylinders; one containing oxygen at high pressure and the other dissolved acetylene also at high pressure.

• It also consists of rubber tubes, pressure regulators, & blow torch.

• The oxygen and acetylene are supplied to the blow torch separately where both of them get mixed together and come out through the nozzle of the blow torch.

Gas Flames A *neutral flame* is obtained by supplying equal volumes of oxygen & acetylene. (Oxygen: Acetylene = 1: 1)

• A neutral flame consists of an inner small whitish cone surrounded by a sharply defined blue flame.

• Most of the oxy-acetylene welding is done with a neutral flame.

Gas Tungsten Arc Welding (GTAW) or Tungsten Inert Gas Welding (TIG)
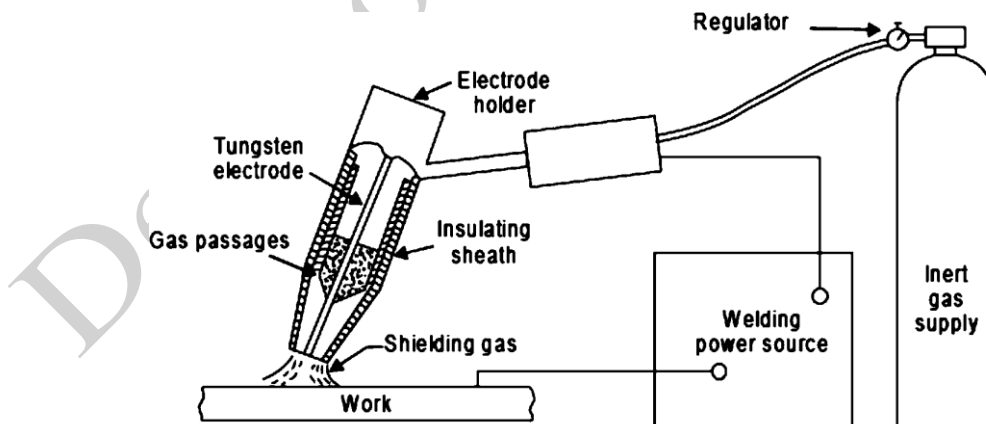
Fig. 2.10 Gas Tungsten Arc Welding (GTAW) or Tungsten Inert Gas Welding (TIG)

Fig. 2.10 shows Gas Tungsten Arc Welding (GTAW) or Tungsten Inert Gas Welding (TIG). Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG)welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by an inert shielding gas (argon or helium), and a filler metal is normally used, though some welds, known as autogenously welds, do not require it. A constant-current welding power supply produces electrical energy, which is conducted across the arc through a column of highly ionized gas and metal vapors known as plasma. GTAW is most commonly used to weld thin sections of stainless steel and non-ferrous metals such as aluminum, magnesium, and copper alloys. This method produces the finest, strongest welds out of all the welding processes. However, it's also one of the slower methods of arc welding.
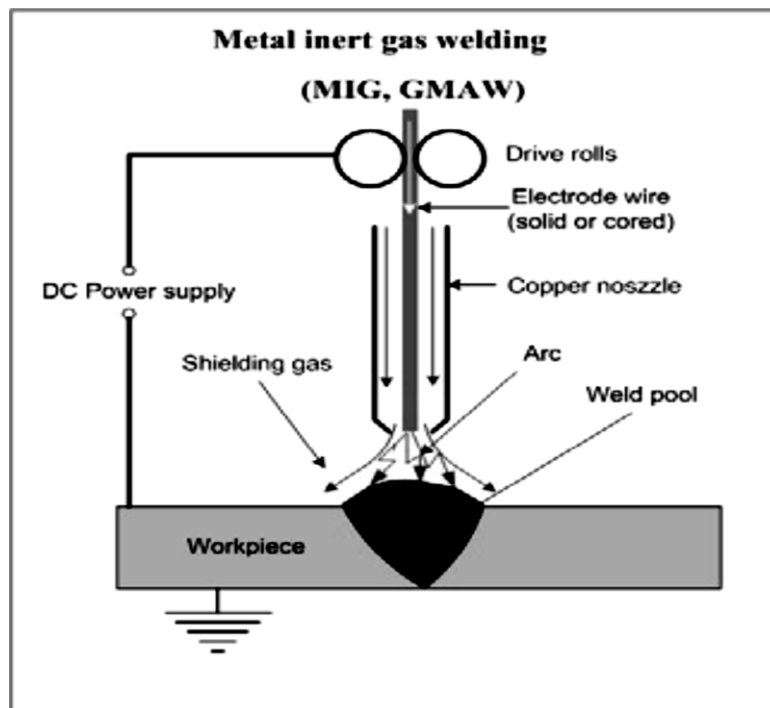
Advantages

1. Superior quality welds
2. Welds can be made with or without filler metal
3. Precise control of welding variables (heat)
4. Free of spatter
5. Low distortion

Disadvantages

1. Lower deposition rates
2. More costly for welding thick sections
3. Excessive electrode consumption
4. Oxidized weld deposit

Gas Metal Arc Welding (GMAW) or Metal Inert gas welding (MIG)

Fig. 2.11 Gas Metal Arc Welding (GMAW) or Metal Inert gas welding (MIG)

Fig. 2.11 shows Gas Metal Arc Welding (GMAW) or Metal Inert gas welding (MIG). Metal inert gas arc welding (MIG) or more appropriately called as gas metal arc welding (GMAW) utilizes a consumable electrode.

It is an arc welding process that uses an arc between a continuous filler metal electrode and the weld pool. The process is used with shielding from an externally supplied gas and without the application of pressure. MIG welding utilizes the heat of an arc between a continuously fed consumable electrode and the work to be welded. The heat of the arc melts the surface of the base metal and the end of the electrode. The metal melted off the electrode is transferred across the arc to the molten pool. The penetration is mainly controlled by welding current. The width of the molten pool is mainly controlled by the travel speed. Shielding of the molten pool, the arc, and the surrounding area is provided by an envelope of gas fed through the nozzle. The shielding gas may be an inert gas, an active gas, or a mixture, surrounds the arc area to protect it from contamination from the atmosphere.

Advantages

1. MIG welding is one of the most popular arc welding processes.

2. Continuous wire feed

3. Automatic self-regulation of the arc length

4. The high deposition rate and a minimal number of stop/start locations

5. The welder has good visibility of weld pool and joint line

6. Little or no post-weld cleaning

7. Can be used in all positions

8. Wide range of application: sheet metal industry, pipe welding.

Disadvantages

1. High level of equipment maintenance

2. No independent control of filler addition

3. Lower heat input can lead to high hardness values

4. Joint and part access is not as good as TIG (tungsten inert gas) welding

2.6 Heat Transfer Applications:
2.6.1 Introduction:

Heat transfer is defined as energy-in-transit due to temperature difference. Heat transfer takes place whenever there is a temperature gradient within a system or whenever two systems at different temperatures are brought into thermal contact. Heat, which is energy-in-transit cannot be measured or observed directly, but the effects produced by it can be observed and measured. Since heat transfer involves transfer and/or conversion of energy, all heat transfer processes must obey the first and second laws of thermodynamics. However unlike thermodynamics, heat transfer deals with systems not in thermal equilibrium and using the heat transfer laws it is possible to find the rate at which energy is transferred due to heat transfer. From the engineer's point of view, estimating the rate of heat transfer is a key requirement. Refrigeration and air conditioning involves heat transfer, hence a good understanding of the fundamentals of heat transfer is a must for a

student of refrigeration and air conditioning. This section deals with a brief review of heat transfer relevant to refrigeration and air conditioning.

Generally, heat transfer takes place in three different modes: conduction, convection and radiation. In most of the engineering problems heat transfer takes place by more than one mode simultaneously, i.e., these heat transfer problems are of multi-mode type.

2.6.2 Heat Transfer:

1. Conduction Heat Transfer:

Conduction heat transfer takes place whenever a temperature gradient exists in a stationary medium. Conduction is one of the basic modes of heat transfer. On a microscopic level, conduction heat transfer is due to the elastic impact of molecules in fluids, due to molecular vibration and rotation about their lattice positions and due to free electron migration in solids. The fundamental law that governs conduction heat transfer is called Fourier's law of heat conduction, it is an empirical statement based on experimental observations and is given by:

$$Q_x = -k.A.\frac{dT}{dx}$$

In the above equation, Q_x is the rate of heat transfer by conduction in x-direction, (dT/dx) is the temperature gradient in x-direction, A is the cross-sectional area normal to the x-direction and k is a proportionality constant and is a property of the conduction medium, called thermal conductivity. The '-' sign in the above equation is a consequence of 2nd law of thermodynamics, which states that in spontaneous process heat must always flow from a high temperature to a low temperature (i.e., dT/dx must be negative). The thermal conductivity is an important property of the medium as it is equal to the conduction heat transfer per unit cross-sectional area per unit temperature gradient. Thermal conductivity of materials varies significantly. Generally it is very high for pure metals and low for non-metals. Thermal conductivity of solids is generally greater than that of fluids. Table 2.3 shows typical thermal conductivity values at 300 K. Thermal conductivity of solids and liquids vary mainly with temperature, while thermal conductivity of

gases depend on both temperature and pressure. For isotropic materials the value of thermal conductivity is same in all directions, while for anisotropic materials such as wood and graphite the value of thermal conductivity is different in different directions. In refrigeration and air conditioning high thermal conductivity materials are used in the construction of heat exchangers, while low thermal conductivity materials are required for insulating refrigerant pipelines, refrigerated cabinets, building walls etc.

Material	Thermal conductivity (W/m K)
Copper (pure)	399
Gold (pure)	317
Aluminum (pure)	237
Iron (pure)	80.2
Carbon steel (1 %)	43
Stainless Steel (18/8)	15.1
Glass	0.81
Plastics	0.2 – 0.3
Wood (shredded/cemented)	0.087
Cork	0.039
Water (liquid)	0.6
Ethylene glycol (liquid)	0.26
Hydrogen (gas)	0.18
Benzene (liquid)	0.159
Air	0.026

**Table 2.3 Thermal conductivity values for various materials at 300 K**

2. **Convection Heat Transfer:**

Convection heat transfer takes place between a surface and a moving fluid, when they are at different temperatures. In a strict sense, convection is not a basic mode of heat transfer as the heat transfer from the surface to the fluid consists of two mechanisms operating simultaneously. The first one is energy transfer due to molecular motion (conduction) through a fluid layer adjacent to the surface, which remains stationary with respect to the solid surface due to no-slip condition. Superimposed upon this conductive mode is energy transfer by the macroscopic motion of fluid particles by virtue of an external force, which could be generated

by a pump or fan (forced convection) or generated due to buoyancy, caused by density gradients.

When fluid flows over a surface, its velocity and temperature adjacent to the surface are same as that of the surface due to the no-slip condition. The velocity and temperature far away from the surface may remain unaffected. The region in which the velocity and temperature vary from that of the surface to that of the free stream are called as hydrodynamic and thermal boundary layers, respectively. Figure 2.12 show that fluid with free stream velocity $U\infty$ flows over a flat plate. In the vicinity of the surface as shown in Figure 2.12, the velocity tends to vary from zero (when the surface is stationary) to its free stream value $U\infty$. This happens in a narrow region whose thickness is of the order of Re_L -0.5 ($Re_L = U\infty L/v$) where there is a sharp velocity gradient. This narrow region is called hydrodynamic boundary layer. In the hydrodynamic boundary layer region the inertial terms are of same order magnitude as the viscous terms. Similarly, to the velocity gradient, there is a sharp temperature gradient in this vicinity of the surface if the temperature of the surface of the plate is different from that of the flow stream. This region is called thermal boundary layer, δt whose thickness is of the order of $(Re_L Pr)$-0.5, where Pr is the Prandtl number.
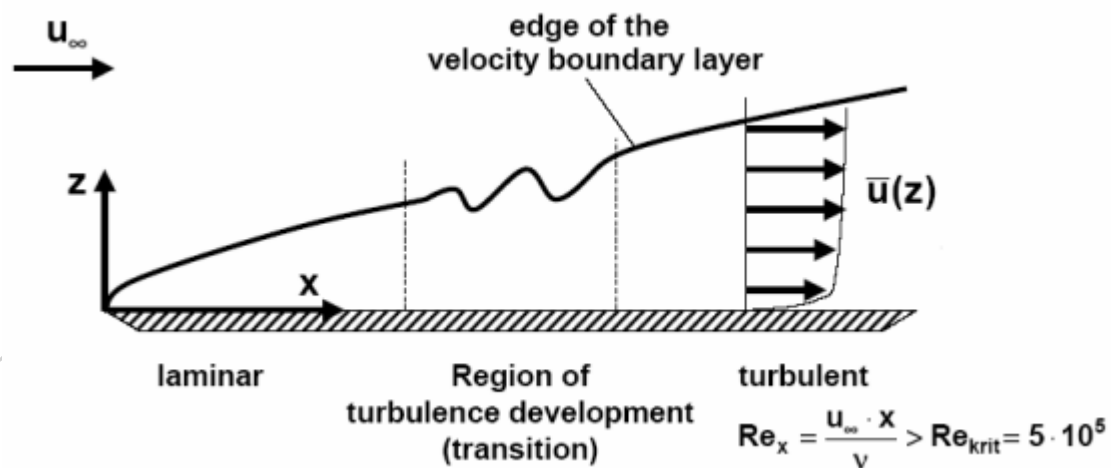
Fig. 2.12 Velocity distribution of flow over a flat plate

convective heat transfer rate can be written in terms of a potential and resistance, i.e.,

$$Q = h_c A(T_w - T_\infty) = \frac{(T_w - T_\infty)}{R_{conv}}$$

where the convective heat transfer resistance, Rconv = 1/(hcA)

3. **Radiation Heat Transfer:**

Radiation is another fundamental mode of heat transfer. Unlike conduction and convection, radiation heat transfer does not require a medium for transmission as energy transfer occurs due to the propagation of electromagnetic waves. A body due to its temperature emits electromagnetic radiation, and it is emitted at all temperatures. It is propagated with the speed of light (3 x 108 m/s) in a straight line in vacuum. Its speed decreases in a medium but it travels in a straight line in homogenous medium. The radiation energy emitted by a surface is obtained by integrating Planck's equation over all the wavelengths. For a real surface the radiation energy given by Stefan Boltzmann's law is:

$$Q_r = \varepsilon.\sigma.A.T_s^4$$

where Q_r = Rate of thermal energy emission, W

ε = Emissivity of the surface

σ = Stefan-Boltzmann's constant, 5.669 X 10-8 W/m^2 .K^4

A = Surface area, m^2

Ts = Surface Temperature, K

The emissivity is a property of the radiating surface and is defined as the emissive power (energy radiated by the body per unit area per unit time over all the wavelengths) of the surface to that of an ideal radiating surface. The ideal radiator is called as a "black body", whose emissivity is 1. A black body is a hypothetical body that absorbs all the incident (all wave lengths) radiation. The term 'black' has nothing to do with black colour. A white coloured body can also absorb infrared radiation as much as a black coloured surface.

**Condensers and evaporators of refrigeration systems:**

Condensers and evaporators are basically heat exchangers in which the refrigerant undergoes a phase change. Next to compressors, proper design and selection of condensers and

evaporators is very important for satisfactory performance of any refrigeration system. Since both condensers and evaporators are essentially heat exchangers, they have many things in common as far as the design of these components is concerned. However, differences exists as far as the heat transfer phenomena is concerned. In condensers the refrigerant vapour condenses by rejecting heat to an external fluid, which acts as a heat sink. Normally, the external fluid does not undergo any phase change, except in some special cases such as in cascade condensers, where the external fluid (another refrigerant) evaporates. In evaporators, the liquid refrigerant evaporates by extracting heat from an external fluid (low temperature heat source). The external fluid may not undergo phase change, for example if the system is used for sensibly cooling water, air or some other fluid. There are many refrigeration and air conditioning applications, where the external fluid also undergoes phase change. For example, in a typical summer air conditioning system, the moist air is dehumidified by condensing water vapour and then, removing the condensed liquid water. In many low temperature refrigeration applications freezing or frosting of evaporators takes place. These aspects have to be considered while designing condensers and evaporators.

Condenser:

As already mentioned, condenser is an important component of any refrigeration system. In a typical refrigerant condenser, the refrigerant enters the condenser in a superheated state. It is first de-superheated and then condensed by rejecting heat to an external medium. The refrigerant may leave the condenser as a saturated or a sub-cooled liquid, depending upon the temperature of the external medium and design of the condenser. Figure 2.13 shows the variation of refrigeration cycle on T-S diagram. In the figure, the heat rejection process is represented by 2-3'-3-4. The temperature profile of the external fluid, which is assumed to undergo only sensible heat transfer, is shown by dashed line. It can be seen that process 2-3' is a de-superheating process, during which the refrigerant is cooled sensibly from a temperature T2 to the saturation temperature corresponding condensing pressure, T3'. Process 3'-3 is the condensation process, during which the temperature of the refrigerant remains constant as it

undergoes a phase change process. In actual refrigeration systems with a finite pressure drop in the condenser or in a system using a zeotropic refrigerant mixture, the temperature of the refrigerant changes during the condensation process also. However, at present for simplicity, it is assumed that the refrigerant used is a pure refrigerant (or an azeotropic mixture) and the condenser pressure remains constant during the condensation process. Process 3-4 is a sensible, sub cooling process, during which the refrigerant temperature drops from T3 to T4.
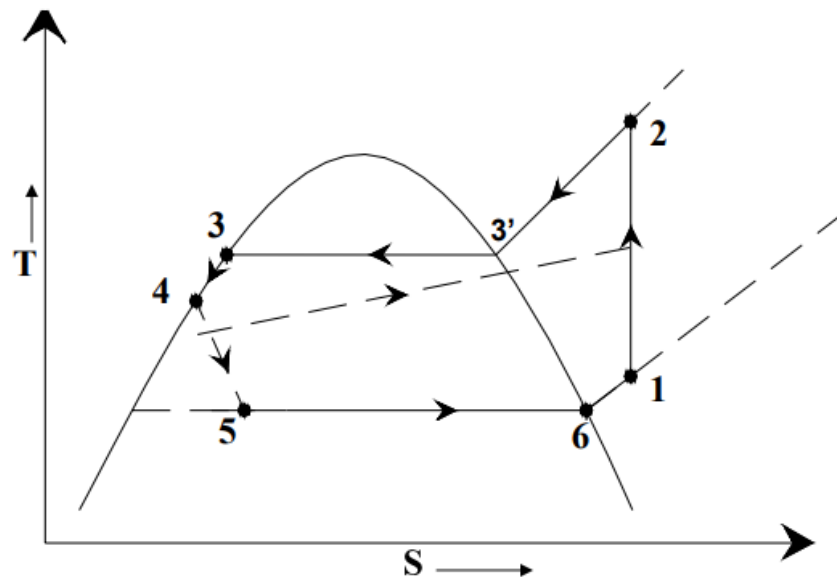
**Fig. 2.13 Refrigeration cycle on T-S diagram**

Evaporator:

- The purpose of the evaporator is to receive low-pressure, low temperature fluid from the expansion valve and to bring it in close thermal contact with the load (Fig. 2.14).
- The refrigerant takes up its latent heat from the load and leaves the evaporator as a dry gas. The function of the evaporator will be to cool gas, liquid or other product loads.
- In most cases air or a liquid is first cooled, and this is then used to cool the load. e.g., in a cold-room air is cooled and this air cools the stored produce and carries away heat leaking through the structure; in a water chiller, water is circulated to cool the load, etc.
- Heat has to pass from the hot water to cold refrigerant.

- The thermal resistances include: Water side heat transfer coefficient, Water side fouling, Conduction in tube wall, Refrigerant side fouling (usually low/negligible), Refrigerant side heat transfer coefficient
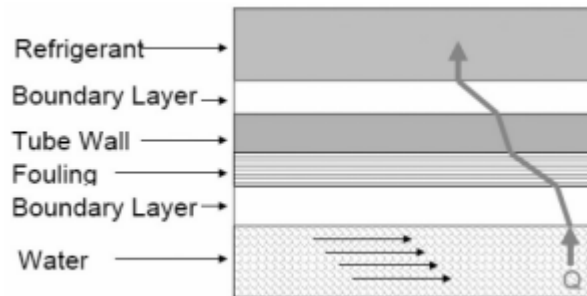
Fig. 2.14 Discuss evaporator refrigeration system

Cooling of Electrical and Electronic Devices:

- Electronic components depend on the passage of electric current to perform their duties, and they become potential sites for excessive heating, since the current flow through a resistance is accompanied by heat generation. Continued miniaturization of electronic systems has resulted in a dramatic increase in the amount of heat generated per unit volume

- The failure rate of electronic equipment increases exponentially with temperature as shown in Fig. 2.15(a) below

(a)   (b)
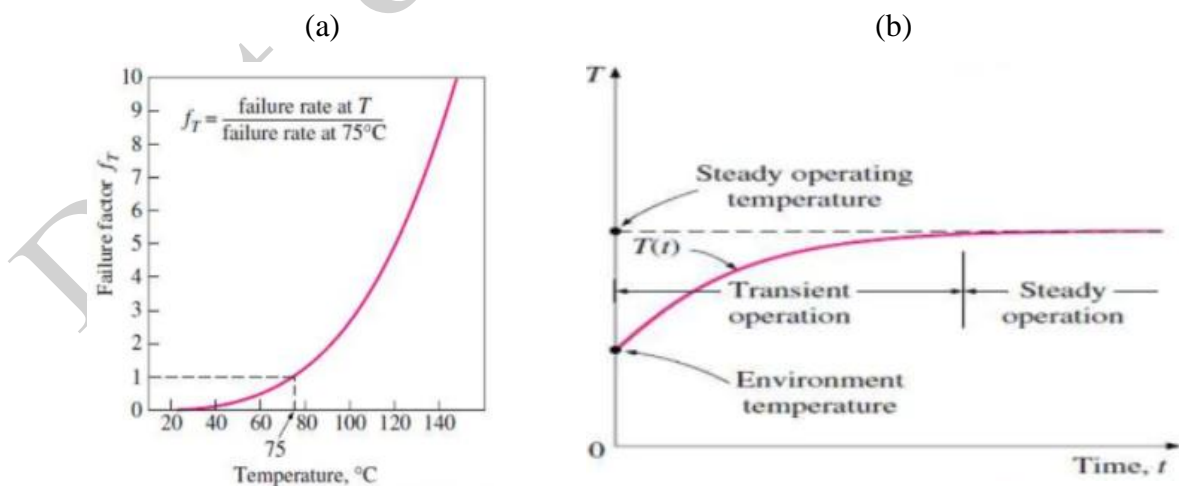
Fig. 2.15 (a) Failure rate of electronic component with temperature, (b) Effect of duty cycle on electronic component

- The first stage of selection and design of a cooling system is the determination of heat dissipation.

- The current flow through a resistance is always accompanied by the heat generation in the amount of $Q= I^2Rt$.

- The duty cycle is another important consideration in the design and selection of a cooling technique.

- Depending upon the load the cooling method is generally chosen. The methods are: Natural convection cooling, Forced convection cooling with air, Immersion cooling with natural convection, Immersion cooling with boiling, Forced circulation of water, Heat Pipe

Active and Passive and Cooling:

- A common problem in product design—particularly in electronics cooling —is managing thermal conditions for optimal efficiency. The core of the challenge is designing energy-efficient microprocessors and printed circuit boards (PCBs) that will not overheat.

- A frequently overlooked aspect of thermal management problem solving is architectural design. Whether it's a private home, an office building, or a dedicated server room, architectural considerations can have a huge impact on the thermal management solutions available.

- To tackle and alleviate the difficulties and inefficiencies that arise as a result of heat, engineers employ different cooling systems to manage conditions. These systems can be divided into two main categories: those with active and with passive cooling techniques. But what is the difference between them?

Passive Cooling:

- The advantages of passive cooling techniques lie in the energy efficiency and lower financial cost, making it an astute systems design choice for the thermal management of both buildings and electronic products.

- Passive cooling achieves high levels of natural convection and heat dissipation by utilizing a heat spreader or a heat sink to maximize the radiation and convection heat transfer modes. In architectural design, natural resources like wind or soil are used as heat sinks to absorb or dissipate heat. This leads to proper cooling of electronic products and thermal comfort in homes or office buildings by keeping them under the maximum allowed operating temperature. A growing trend in this regards can be witnessed in what is commonly known in the industry as passive houses.

- To sum it up—passive thermal management is a cost-effective and energy-efficient solution that relies on heat sinks, heat spreaders, heat pipes or thermal interface materials (TIM) to maintain optimal operating temperatures.

Active Cooling:

- Active cooling, on the other hand, refers to cooling technologies that rely on an external device to enhance heat transfer. Through active cooling technologies, the rate of fluid flow increases during convection, which dramatically increases the rate of heat removal.

- Active cooling solutions include forced air through a fan or blower, forced liquid, and thermoelectric coolers (TECs), which can be used to optimize thermal management on all levels. Fans are used when natural convection is insufficient to remove heat. They are commonly integrated into electronics, such as computer cases, or are attached to CPUs, hard drives or chipsets to maintain thermal conditions and reduce failure risk.

- The main disadvantage of active thermal management is that it requires the use of electricity and therefore results in higher costs, compared to passive cooling.