Module - 4

Engineering materials and joining processes

All metals may be classified as ferrous or nonferrous. A ferrous metal has iron as its main element. A 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.

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

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

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:

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

Engineering Materials

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 house hold 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 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 intrinsic modification, minor alloying or heat treatment is carried out. In extrinsic modification, external reinforcements are added to the parent material to alter its properties in order to meet the specific design requirements.

The engineers are then entrusted with the task of finding suitable techniques which would lead to high quality cost-effective processing of these materials. In order to achieve this objective, it is imperative for all engineers to have a fundamental understanding of the existing materials and their processing techniques. It has been found that there are adequate of courses in the curriculum of various universities where the processing techniques for metals are dealt in detail. The processing of non-metals is usually not covered as a core subject at the under-graduate level and therefore the engineers do not have a fundamental understanding about the processing of important non-metals such as plastics and ceramics. The course has been designed to study the basic nature of different non-metals and the manufacturing processes associated thereof. The various non-metals covered in the course include glasses, ceramics, plastics and different types of composite materials.

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) Deformative Processes

c) Material Removal Processes

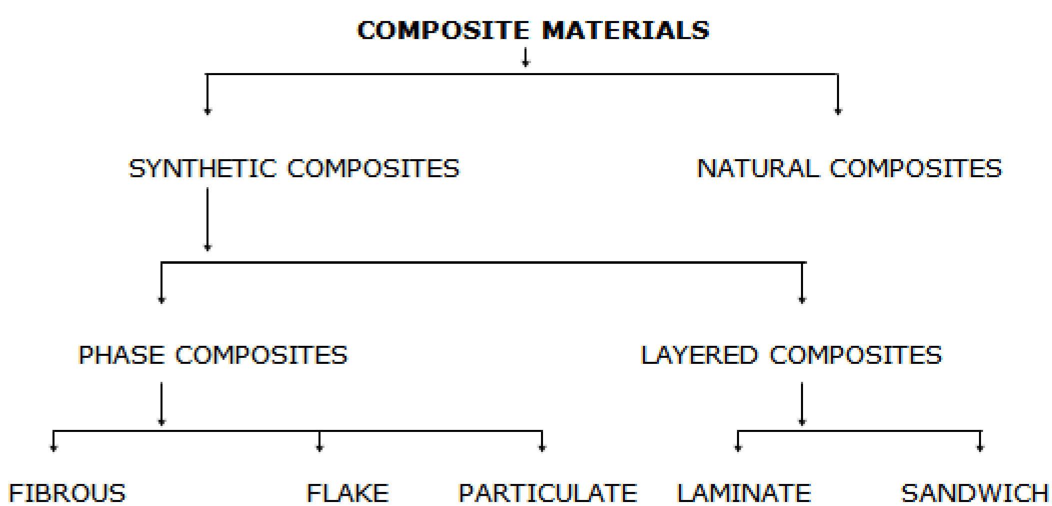
d) Joining Processes

e) Finishing Processes

Most of the engineering materials are processed either individually or in combination by the above mentioned processes. The processes can further be classified as conventional and advanced processes. The specific application area of each will depend on the 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.

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.



Classification of composites I (based on matrix material)

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.

Ceramic Matrix Composites (CMC)

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

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 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 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 form of continuous fibers.
   I. Unidirectional orientation of fibers.
   II. Bidirectional 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 **matrix** of another material are the best example 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 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 on 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 till failure occurs and show decreased failure strain, when loaded in tension and compression.

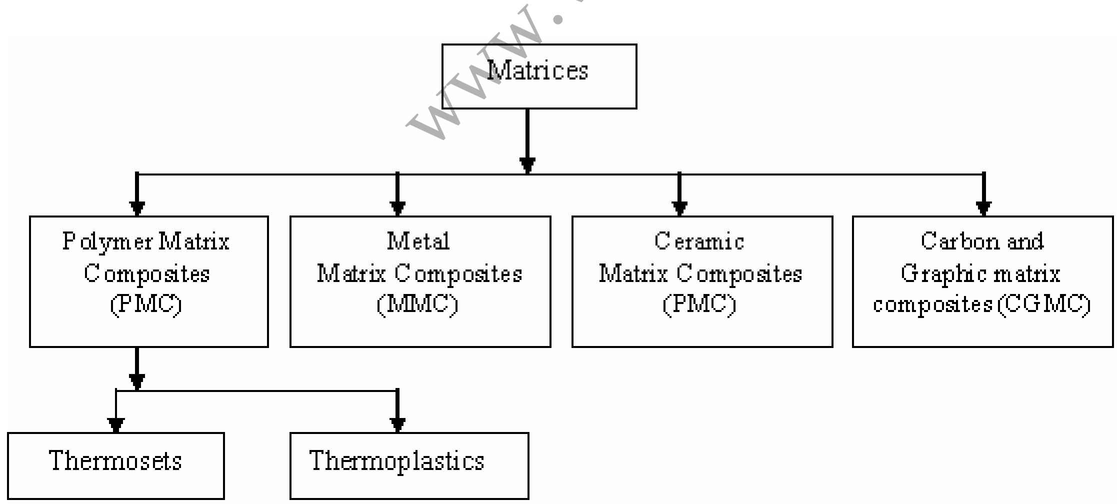
Classification of Composites

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 - fibre **reinforced composites**, **laminar composites** and **particulate composites**. Fibre Reinforced composites (FRP) can be further divided into those containing discontinuous or continuous fibres.
- **Fibre Reinforced Composites** are composed of fibres embedded in matrix material. Such a composite is considered to be a discontinuous fibre or short fibre composite if its properties vary with fibre length. On the other hand, when the length of the fibre 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 fibre reinforced. Fibres are small in diameter and when pushed axially, they bend easily although they have very good tensile properties. These fibres must be supported to keep individual fibres 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



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 moulding 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 exaggerated melting point. Another advantage is that the process of softening at elevated temperatures can reversed to regain its properties during cooling, facilitating applications of **conventional compress techniques** to mould 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, 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-to-weight ratios of resulting composites can be higher than most alloys.

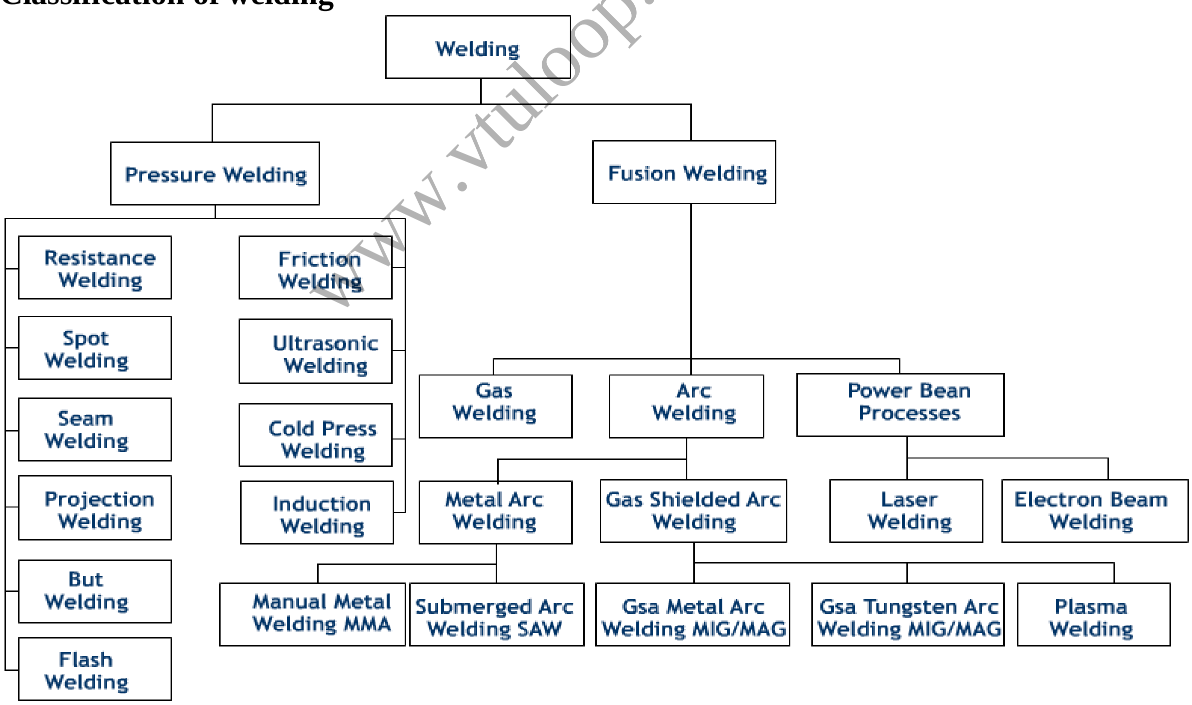
The melting point, physical and mechanical properties of the composite at various temperatures determine the service temperature of composites. Most metals, ceramics and compounds can be used with matrices of low melting point alloys. The choice of reinforcements becomes more stunted with increase in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

Soldering, Brazing and Welding:

Welding:

Welding is defined as the joining of two metal pieces, together to produce essentially a single piece of metal.

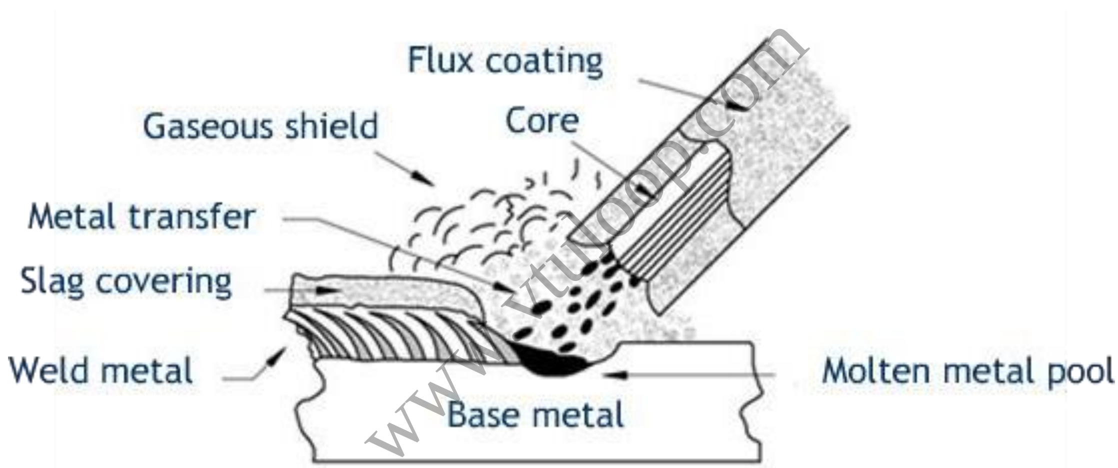
Classification of welding



Types of Welding

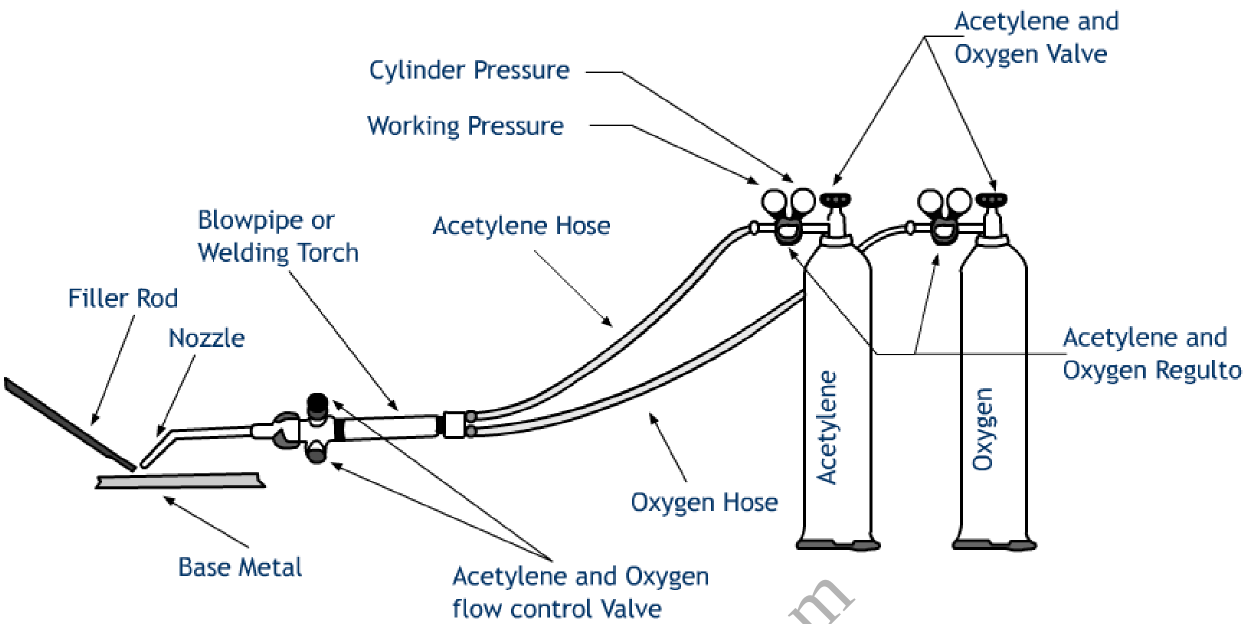
1) **Fusion Welding:** joining two metal pieces is heated up to molten state and allowed to solidify, also called as no-pressure welding.
   Ex- Arc welding and Gas welding
2) **Pressure welding:** joining parts to be heated up to plastic state and applying external pressure.
   Ex- Resistance welding and Forge welding.

Electric Arc Welding



Arc welding is one of several fusion welding processes for joining metals. By applying intense heat through a electric arc, metal at the joint is melted and caused to intermix - directly, or with an intermediate molten filler metal. Upon cooling and solidification, a metallurgical bond is created. Since the joining is an intermixture of metals, the final weldment potentially has the same strength properties as the metal of the parts.

Oxy-Acetylene Welding



This is a common gas welding process. Acetylene is the fuel gas used. Acetylene produces high heat content in the range of 3200^0 C than other fuel gases. Acetylene gas has more available carbon (92.3 %) and hydrogen (7.7 %) by weight. The heat is released when the carbon breaks away from hydrogen to combine with O_2 and burn.

$$C_2H_2+O_2 = 2CO+H_2+Heat$$

Depending up on the gas pressure required for welding or cutting oxy acetylene welding is classified into two parts:

Low pressure System and

High-pressure system

Soldering:

Soldering is a method of joining two thin metal pieces using a dissimilar metal or an alloy by the application of heat.

- Temperature is range of 150 to 350 degree.
- Application of flux is externally, usually rosin or borax.
- Soldering application will be electronics circuits.

Advantages of soldering

1) Solder joints are easy to repair
2) Solder joints are corrosion resistance.
3) Low cost and easy to use.
4) Skilled operator is required.

Brazing:

Brazing is a method of joining two similar or dissimilar metals using a special fusible alloy.

The filler metal melts and diffuses over the joint placed.

- The filler metal is called as **Spelters.**
- The flux used is borax or boric acid.
- The brazing is used in copper alloys applications.
- The temperature range is 450 to 900 degree.

Differences between soldering, brazing and Welding

Sl. No.	Welding	Soldering	Brazing
1	These are the strongest joints used to bear the load. Strength of a welded joint may be more than the strength of base metal.	These are weakest joint out of three. Not meant to bear the load. Use to make electrical contacts generally.	These are stronger than soldering but weaker than welding. These can be used to bear the load upto some extent.
2	Temperature required is up to 3800^{o}C of welding zone.	Temperature requirement is up to 450^{o}C.	It may go to 600oC in brazing.
3	Workpiece to be joined need to be heated till their melting point.	No need to heat the workpieces.	Work pieces are heated but below their melting point.
4	Mechanical properties of base metal may change at the joint due to heating and cooling.	No change in mechanical properties after joining.	May change in mechanical properties of joint but it is almost

			negligible.
5	Heat cost is involved and high skill level is required.	Cost involved and skill requirements are very low.	Cost involved and sill required are in between others two.
6	Heat treatment is generally required to eliminate undesirable effects of welding.	No heat treatment is required.	No heat treatment is required after brazing.
7	No preheating of workpiece is required before welding as it is carried out at high temperature.	Preheating of workpieces before soldering is good for making good quality joint.	Preheating is desirable to make strong joint as brazing is carried out at relatively low temperature.