Joining processes

Almost all products are assemblies of a large number of components. Some of the components or sub-assemblies can move with respect to each other, others are physically fixed together, with no relative motion possible. The first type of connection is called a ***kinematic joint***, and the second type is called a ***rigid joint*** (or a ***structure***). Both types of joints are important in manufacturing, and there are many ways of achieving such joints. The process and methods used for joining depend on the type of joint, the required strength, the materials of the components being joint, the geometry of the components, and cost issues. In this lecture, we study some of the common methods of joining.

Why do we need joining?

(a) To restrict some degrees of freedom of motion for components (i.e. to make mechanisms).

(b) A complex shaped component may be impossible/expensive to manufacture, but it may be possible/cheaper to make it in several parts and then join them.

(c) Some products are better made as assemblies, since they can be disassembled for maintenance.

(d) Transporting a disassembled product is sometimes easier/feasible compared to transporting the entire product. A good example of this is the beautiful Tsing Ma bridge of Hong Kong; individual sections were fabricated, raised to the correct position, and then welded/riveted together to construct the structure.

Figure (1): A section of Tsing Ma Bridge being lifted, before joining.

Welding is a process which two materials, usually metals, are permanently joined together through localized coalescence, resulting from a suitable combination of temperature, pressure and metallurgical conditions.

Various welding processes have been classified in three main groups, namely:

1- Fusion Welding

1-1 Oxyfuel gas welding (OFW)

1-2 Arc welding (AW)

1-2-1 Gas Shielded Arc Welding or Shielded Metal Arc Welding (SMAW)

- Metal Inert Gas Welding
- Tungsten Inert-Gas Arc welding

1-3 Brazing and Soldering

1-4 Resistance welding (RW)

1-4-1 Resistance Spot Welding (RSW)

1-4-2 Resistance Seam Welding (RSEW)

1-5 Submerged Arc Welding (SAW)

2- Solid state welding

2-1 Friction Welding (FRW) (Inertia Welding)

- Friction Stir Welding (FSW)

2-2 Cold welding

2-2 Ultrasonic welding

- Ultrasonic spot welding
- Ultrasonic ring welding
- Ultrasonic line welding
- Ultrasonic continuous Seam Welding

2-3 Explosive Welding (EXW)

3- Unique processes.

3-1 Electron Beam Welding (EBW)

3-2 Plasma Arc Welding(PAW)

3-3 Laser Beam Welding

1- Fusion Welding

Welding is the most common joining process for metals. In fusion welding, the joint is made by melting the metal at the interface, so that upon solidification, the components are fused, or joined together. In many cases, extra metal is melted along the joint, to completely fill the joint region.

1-1 Oxyfuel gas welding (OFW)

Oxyfuel gas welding is a fusion welding process, the metals being joined are melted at the point where welding occurs, where no pressure is applied.

Because a slight gap exists between the pieces being joined, filler material usually must be added in the form of a wire or rod (which is called **electrode**) that is melted in the flame or in the pool of weld metal. Composition of the electrode material should be similar (compatible) to the workpiece materials which are going to be welded (parent materials).

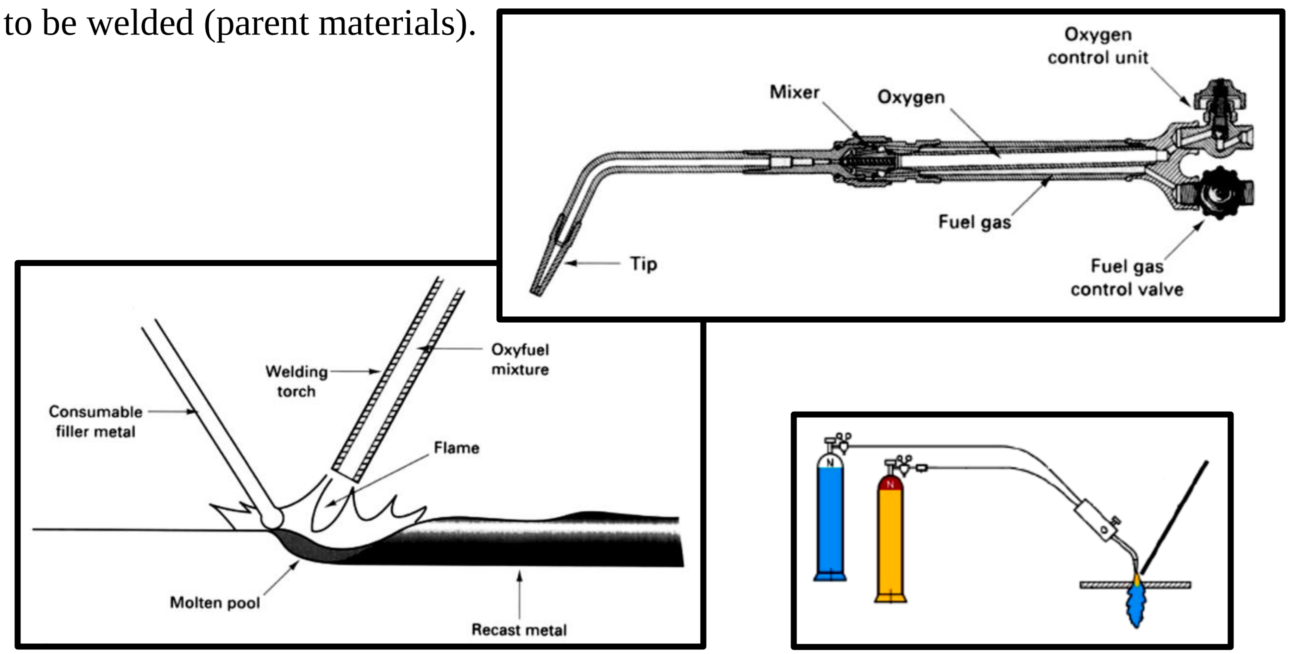


Figure (2):The oxyfuel gas welding theory and arrangments

Oxyfuel gas welding covers a group of welding processes that utilize as the heat source a flame resulting from burning of a fuel gas and oxygen, mixed in

proper proportions.

● A welding torch is used to mix and burn the gases.

● Acetylene is the principal fuel gas employed for this process.

● Acetylene gas is obtained by a reaction between Calcium Carbide and water.

● The combustion of oxygen and acetylene produces a temperature of about 3500°C.

The acetylene gas welding is a mixture of acetylene gas (C_2H_2) and oxygen gas are mixed; acetylene is highly flammable, so the mixture can be lighted and burns generates very high temperatures of up to 3000°C. The flame is used to melt the metal at the joint, along with a filler rod to provide some extra material to fill the gap. The filler rod is coated with **flux**.

Fluxes The flux is a chemical with two uses: part of it evaporates, and the vapor surrounds the region around the molten metal, preventing oxidation. Another part of the flux melts, and dissolves impurities and metal oxides; since these are lighter than the molten metal, they float to the surface and can be removed by a finishing process later.

Fluxes can be added as a powder, or the welding rod can be dipped in a flux paste. Fluxes play a very important part by dissolving oxides that may be on the surface prior to heating, and by preventing the formation of oxides during heating.

1-2 Arc welding (AW)

Arc welding is a fusion welding process, the metals being joined are melted at the point where welding occurs. Heat is obtained by an **arc** between the work and electrode. The process is useful, versatile, and widely used. But, for most applications, weld quality depends on the skill and integrity of the operator.

Here, the metal is heated by maintaining a very high voltage between the electrode and the metal. This results in dielectric breakdown of the air gap, causing

a discharging arc. The temperature at the arc can reach up to 30,000°C (almost ten times oxy-fuel torches). Notice from figure (3 b), that the metal is used as one electrode, and the filler rod as the other electrode; either DC or AC can be used, with typical current ranging between 50A ~300A and typical power of 10kW or more. Typically, DC welders are used for sheet metal, while high power

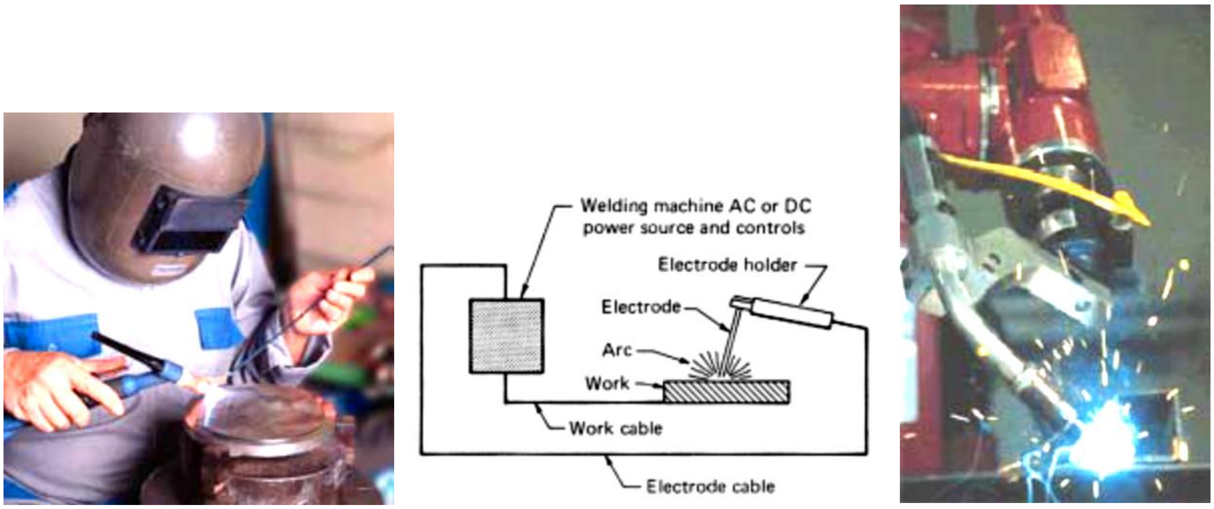


Figure (3): (a) Gas welding (b) Schematic of Arc welding (c) Arc welding is easier to automate using Robots (why?)

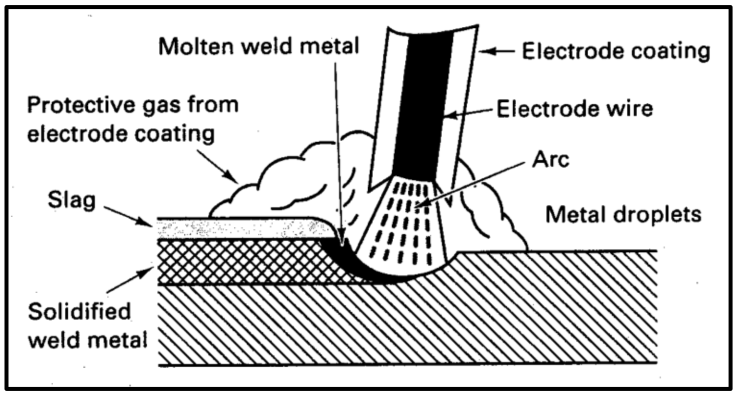
requirements of thick members need AC supply.

All arc welding is done with metal **electrodes**. In some applications, the electrode is consumed, i.e. melted and thus supplies the needed filler metal. In some other applications of arc welding, the electrode is made of tungsten, which is not consumed by the arc except by relative slow vaporization. Here a separate filler wire must be added to supply the needed metal, i.e. to be consumed. Composition of the consumed material should be similar (compatible) to the parent materials.

Uses electrodes, which are mostly finite-length sticks, that consist of metal wire, upon which is extruded a coating containing chemical components that add a number of desirable characteristics, including all or a number of the following.

- Add additional filler metal.

- Act as a flux to remove impurities from the molten metal.
- Provide a protective atmosphere.
- Provide a protective slag to accumulate impurities, prevent oxidation, and slow down the cooling of the weld metal. (The slug should be removed afterwards.)
- Stabilize the arc.
- Reduce weld-metal spatter
- Add alloying elements.
- Affect arc penetration.
- Influence the shape of the weld bead.



1-2-1 Gas Shielded Arc Welding or **Shielded Metal Arc Welding (SMAW)**

- Fast and economical, since there is no frequent changing of electrodes, as with stick-type electrodes.
- There is no slag formed over the weld.
- The process can be automated, can be performed by industrial robots.
- An inert gas is supplied with sufficient flow to form an inert shield around the arc and the molten pool of metal, thereby shielding them from the atmosphere.
- virtually any metal, they are used primarily for welding nonferrous metals.

The most common form is:

- **Metal Inert Gas Welding (MIG Welding)**

Here, and inert gas such as Argon or an Argon/Helium mixture is injected to surround the region of the weld. This ensures that the molten metals are shielded from the atmospheric oxygen, and therefore do not oxidize. The electrode may be consumable (i.e. made from the filler material) or non-consumable.

Another common form of shielded metal arc welding is:

- **Tungsten Inert Gas Arc welding** (**TIG Welding**).

Here, the arc is formed between a non-consumable tungsten electrode and the metal being welded. Gas is fed through the torch to shield the electrode and molten weld pool. If filler wire is used, it is added to the weld pool separately. TIG welding can yield better quality and more precise welds. Welding Aluminum almost always requires TIG or MIG welding, since Al oxidizes easily, and molten Al must not be exposed to oxygen. TIG is also commonly used for welding Titanium, Magnesium, especially thin section welding.

The tungsten electrode is held in a special holder through which an inert gas is supplied with sufficient flow to form an inert shield around the arc and the molten pool of metal, thereby shielding them from the atmosphere. Produces very clean welds, and no special cleaning or slag removal is required because no flux is employed.

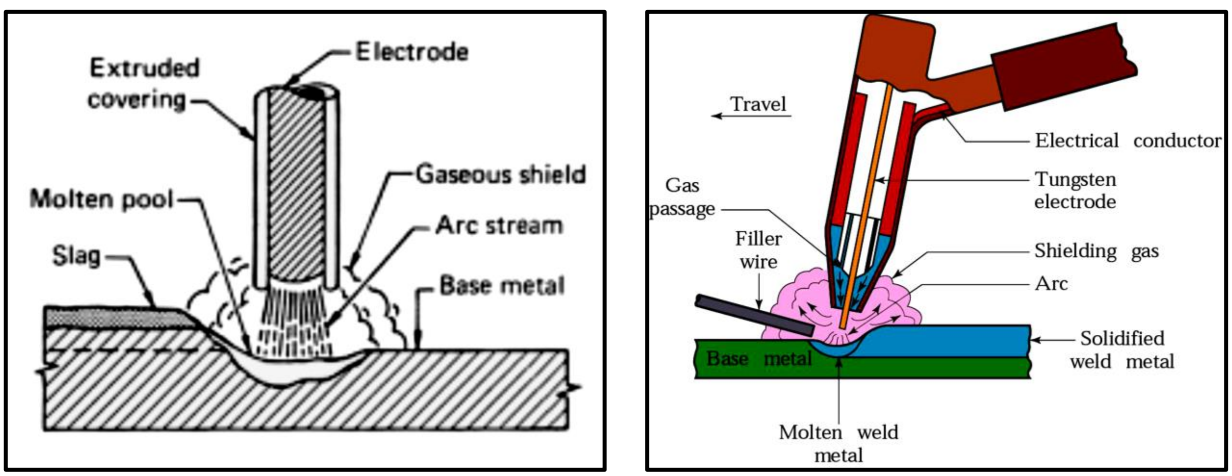


Figure 3 (a) MIG welding (b) TIG welding

1-3 Brazing and Soldering Welding

Brazing and soldering are somewhat similar processes with some common properties as given below.

- The compositions of the brazing and soldering alloys, which are nonferrous alloys, are significantly different from the base metals (materials that are going to be joined).
- The melting point of these alloys are lower than that of the base metal.
- Therefore, during the process the base metals are not melted.
- Heating a brazed or soldered joint above the melting point of the used alloy may destroy the integrity of the joint.

- For both processes, the surfaces should be cleaned beforehand.
- Fluxes play a very important part by dissolving oxides that may be on the surface prior to heating, and by preventing the formation of oxides during heating.
- Borax has been a commonly used brazing fluid.
- Although fluxes will dissolve modest amounts of oxides, they are not cleaners.
- Before a flux is applied, dirt, particularly oil, should be removed from the surfaces that are to be joined.
- After the process flux residues must be completely removed, since most of them are corrosive.

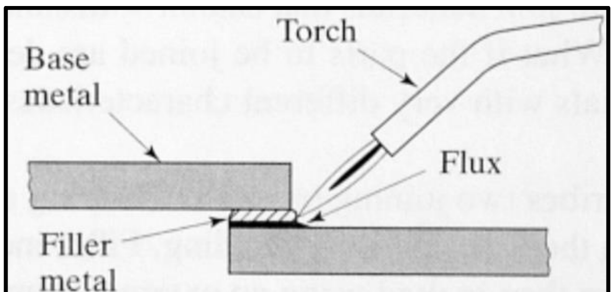
❖ Brazing Welding

In brazing, the filler material is a metal with melting temperature lower than that of the metals being joint. The filler is placed in the joint (or near it), and the metals are heated till the filler melts (but not the components). The melted filler material fills the joint and, on cooling, creates a brazed joint. In some cases, oxy-acetylene gas welding may be used for this process, with the filler made of a low melting temperature metal rod. Fluxes are used in brazing, for the same reasons as in welding.

Melting temperature of braze material is above 450°C (The 450°C, which is an arbitrary value, is set to distinguish brazing from soldering).

Braze materials are:

- copper (for brazing of steel, HSS, and tungsten carbide),
- copper alloys (e.g. brazing brass, manganese bronze),
- silver (for brazing titanium),
- silver alloys,
- aluminum-silicon alloys.



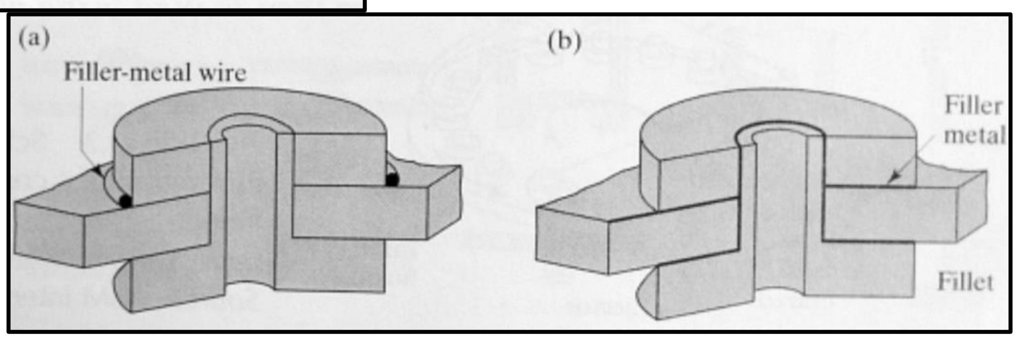


Figure (6): (a) Brazing (b) Furnace brazing

Capillary attraction forces plays an important role in distributing the braze metal to flow in the joint. For capillary attraction to exist, the clearance between the parts being joined must be quite small.

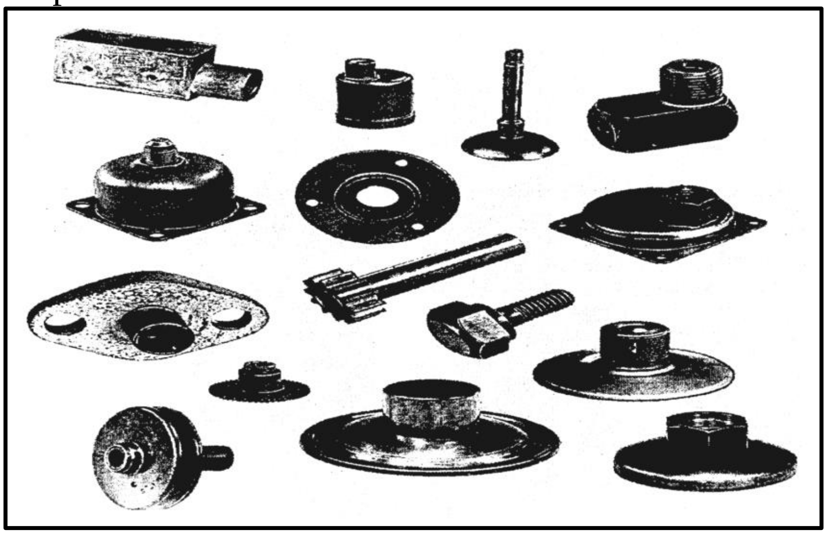
A brazed joint derives its strength from a combination of the braze metal and the base-metal alloy that is formed and the penetration of the low-viscosity brazing metal into the grain boundaries of the base metal.

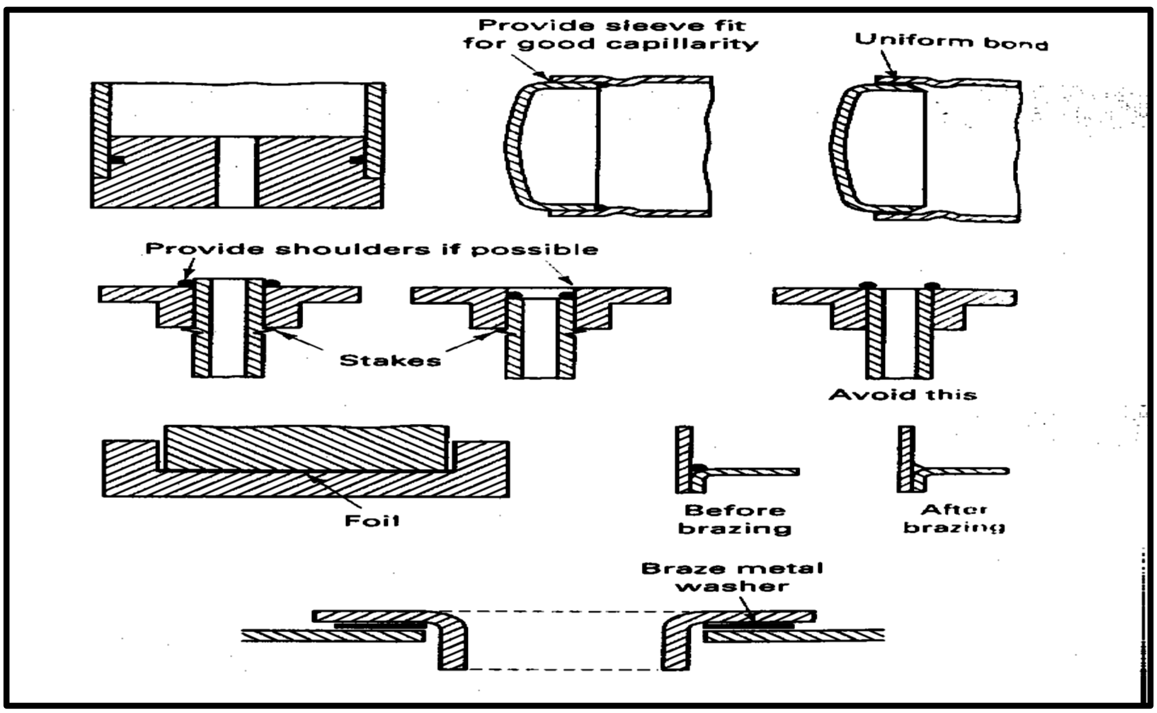
Advantages of Brazing

1. Virtually all metals can be joined.
2. Less heating is required than for welding; the process can be performed more quickly and more economically.
3. Since lower temperatures are used, fewer difficulties due to distortion are encountered, and thinner and more complex assemblies can be joined successfully.
4. Many brazing operations are adaptable to automation.

Heating Methods used for Brazing

1. Torch brazing
2. Furnace brazing
3. Salt bath brazing
4. Dip brazing
5. Induction brazing
6. Resistance brazing





❖ Soldering Welding

Melting temperature of solder material, called solder, is below 450°C (The 450°C, which is an arbitrary value, is set to distinguish brazing from soldering). Solder is a very low T_m metal alloy of lead and tin with the addition of a very small amount of antimony, melting at around 200°C. This is very useful to create joints in electronic circuits, which need not withstand large forces, but should be made with low energy, low temperature processes (why ?). We shall look at different types of soldering when we study electronics manufacturing processes.

Heating Methods used for Soldering

1. Electric soldering irons or guns
2. Dip soldering (e.g. electronics work, automobile radiators)
3. Induction heating (Used for a large number of identical parts)
4. Heating by infrared sources (For low melting point solders)
5. Furnace heating (Seldom used)
6. Salt-bath heating (Seldom used)